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THE Association was organized in Boston, Mass., on June 21, 1882, with the object of providing its members with means of social intercourse and for the exchange of knowledge pertaining to the construction and management of water works. From an original membership of only TWENTY-SEVEN, its growth has prospered until now it includes the names of 900 men. Its membership is divided into six classes, viz.:

A Member shall be an officer or employee of a public or private water works, an engineer, chemist or other person qualified to aid or interested in the advancement of knowledge relative to water works.

An Honorary Member shall be a person of acknowledged eminence in some branch of water supply or of engineering.

A Junior shall be not less than eighteen years nor more than twenty-five years of age, a student or connected with water supply work.

An Associate shall be either a person, firm or corporation engaged in manufacturing or furnishing materials or supplies for the construction or maintenance of water works.

A Corporate Member shall be either a Water Board, Commission, Company or Municipal Corporation.

The initiation fees and annual dues are as follows:

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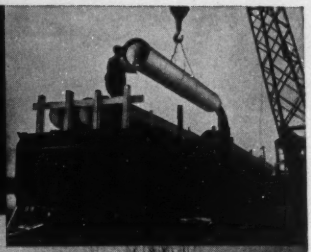
This Association has at least eight regular meetings each year, of which four are held in Boston, one in northern New England, one in southern New England, and one, the annual convention, held in September on such date as the Executive Committee may designate.

16" and UP



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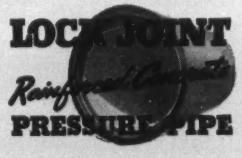

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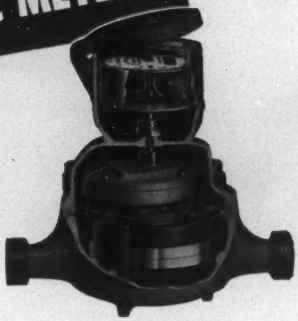

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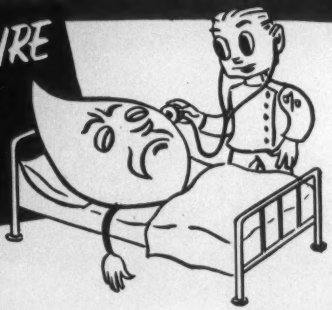

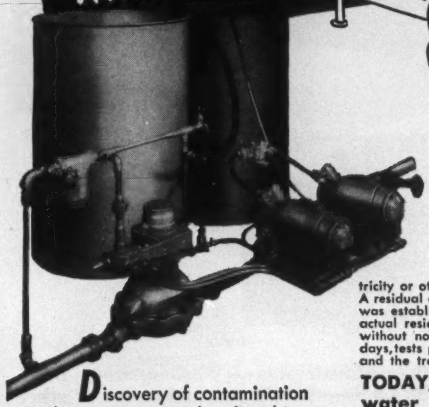

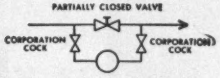

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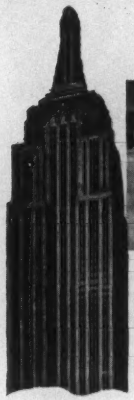

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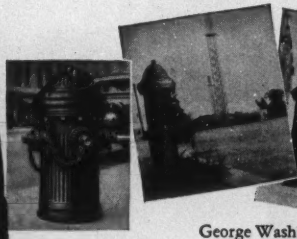

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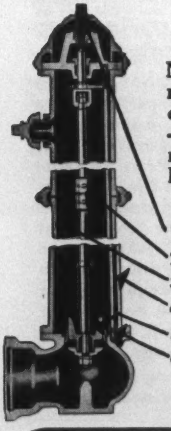

New York — Philadelphia — Washington — Baltimore — St. Louis — Providence and scores of other cities throughout the nation use SMITH hydrants — and not without good reason. A few of these reasons can easily be seen upon inspection of the hydrant section shown at the left.

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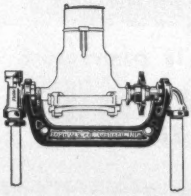

Ford Yokes are made in styles to meet every meter setting condition—indoors or out. Regardless of location, the Ford Yoke makes settings easier, removes pipe strains, saves labor and keeps meter connections permanently aligned for fast changes. Roughly, Ford Yokes are made in three styles:

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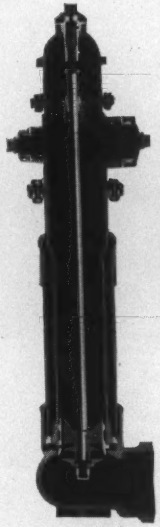

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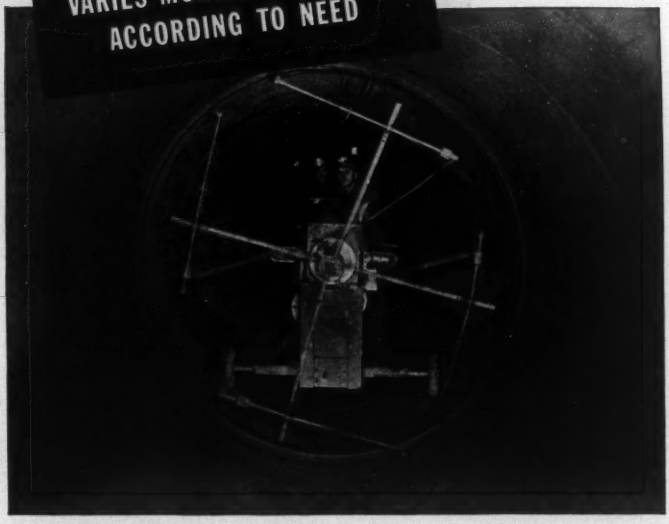
▶▶▶ PIPE LINING FACTS NO. 4



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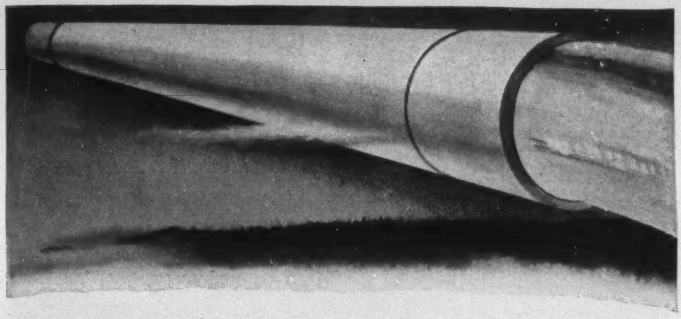

Saving precious water for a thirsty

Municipal consumption of water in the United States has risen from two billion to over twelve billion gallons per day during the last fifty years.

In many areas, this rapid increase in the use of water is posing a serious problem. It means that water supplies must be conserved to the limit if they are to continue to meet an ever-growing demand.

It is not surprising, therefore, that more and more water-works officials are seeking ways to cut water losses as one practical step toward the solution of this problem.

Since recent studies indicate that many localities are losing as much as 10% of water pumped because of underground leakage, an important question to be answered in any water conservation program is this: "How can I plan to reduce this major cause of water loss to a minimum?"

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The unusual success of Transite Pipe in combatting underground water losses is due to a combination of two factors: (1) The design of the Simplex Coupling used for assembly, and (2) the ability of the pipe to maintain its strength in service.

Because flexibility is engineered into the Simplex Coupling, this factory-made joint is virtually unaffected by pipe line stresses that so often result in the loosening and failure of conventional type joints. No particular skill is required for its proper assembly, which is readily checked by the use of a simple gauge immediately after the pipe ends are joined.

Moreover, Transite's maintained strength provides a further safeguard against costly underground water losses. In thousands of installations representing a wide variety of municipal soils, this asbestos-cement pipe has proved its exceptional ability to withstand corrosion . . . to maintain its strength under conditions which have seriously impaired the structural integrity of other pipe materials.

Reducing the amount of "water pumped but not paid for" on your books—a saving in dollars as well as water—is only one of many important economies which Transite Pipe can offer you. Savings on installation, savings on pumping costs, savings on maintenance . . . these are further reasons why you will want all the facts about this modern asbestos-cement pipe developed by Johns-Manville to carry water more efficiently.

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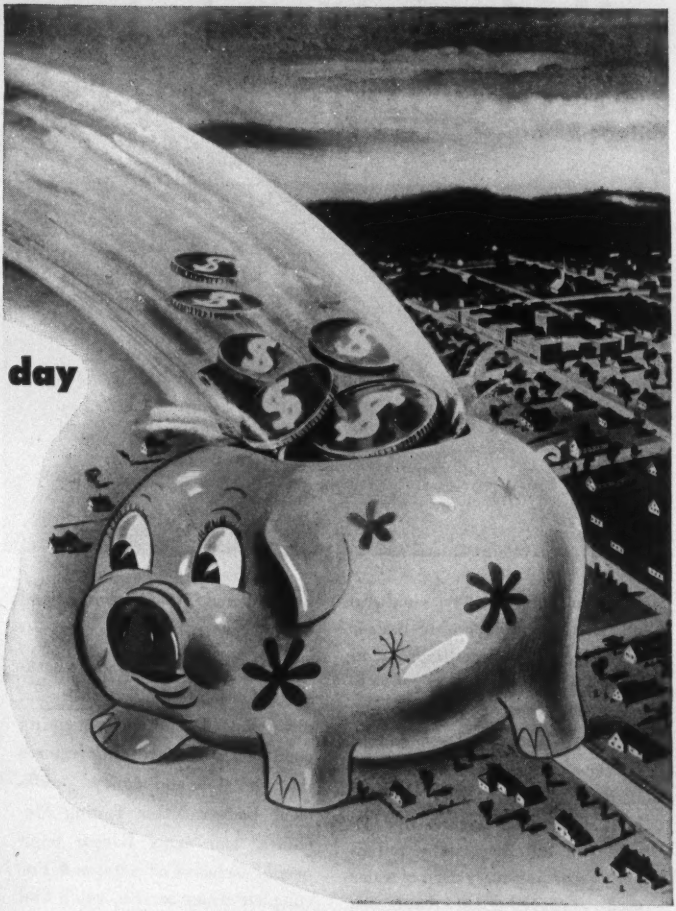

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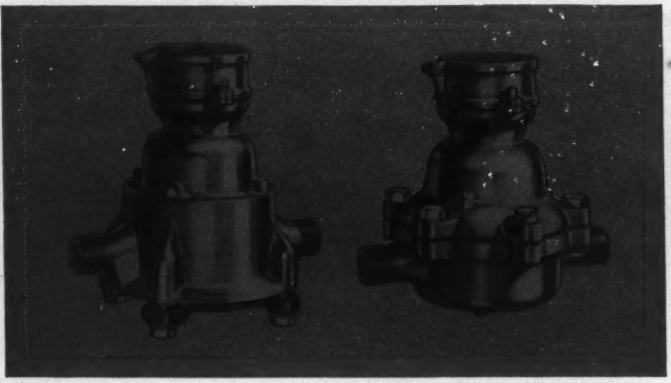

Yes, you'll find every type and size of meters in the complete Badger line . . . but you get *more than meters* from Badger. You get complete meter service:

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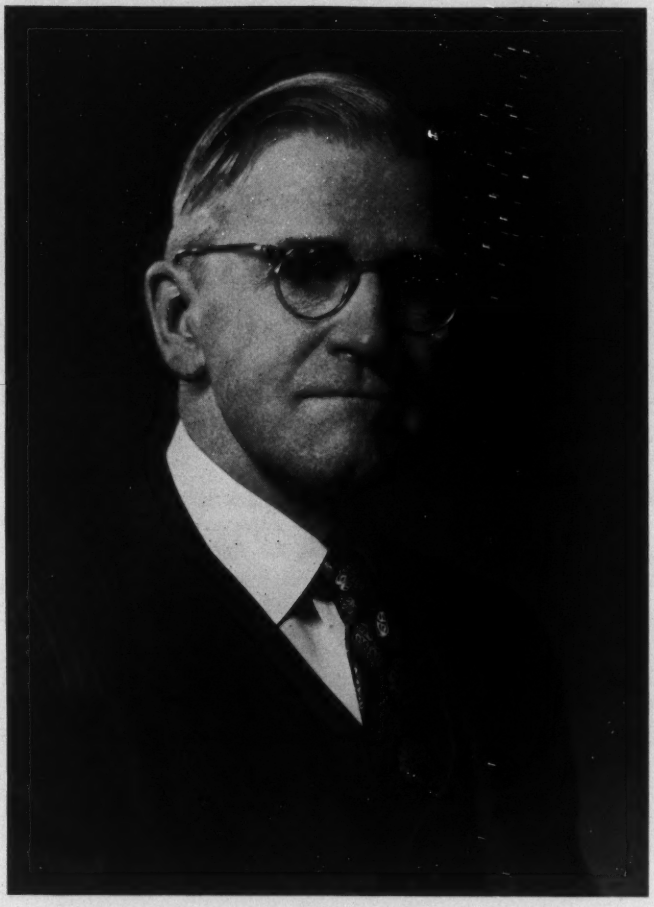

THOMAS R. CAMP

President of the New England Water Works Association, 1950-51.

New England Water Works Association
ORGANIZED 1882

VOL. LXV MARCH, 1951 NO. 1

This Association, as a body, is not responsible for the statements or opinions of any of its members

WATER SUPPLIES FOR ARMY BASES IN ALASKA

BY W. L. HYLAND† AND G. M. REECE‡

[*Read December 15, 1949.*]

WATER-SUPPLY problems in Alaska are quite different from those in more temperate zones, largely because of climatic conditions. Except for areas adjacent to the coastline, much of Alaska north of the 60th parallel is a so-called "permafrost" area; that is, ground below the depth of penetration of seasonal frost is permanently frozen and has been in this condition since the Ice Age, about one million years ago.

This frozen condition is not uniform, but varies between localities and even in the same locality. The permafrost may be near the surface or it may be some distance below the surface, and may be a few feet or 1,000 ft or more in thickness. The temperature of permafrost varies from 25° F. near the active layer to almost 32° F. at great depths. Water pipes going through the frozen material must be protected. It has been our practice to provide concrete boxes or utilidors* for the water pipes and for the sewer and steam pipes as well.

In the permafrost region, swamps, lakes and rivers are prominent features of the landscape and the terrain appears to abound with water. However, locating an ample all-year-round supply is often difficult. The rivers and lakes freeze to a great depth, at times to a depth in excess of 6 ft, and the protection of an intake in a relatively shallow river or lake in a flat terrain—such as the countryside around Fairbanks—would be costly. In addition, many of the streams are heavily laden with glacial silt that further limits their use as a source of water supply. The most dependable source of water supply in a permafrost area is deep wells driven into strata be-

†Partner, Fay, Spofford & Thorndike, 11 Beacon St., Boston 8, Mass.
‡Engineer, Fay, Spofford & Thorndike.

*See paper entitled "Utilidors for Water, Sewer and Steam Utilities in Arctic Regions," by W. L. Hyland and M. H. Mellish, in *Civil Engineering*, January, 1949.

low or between the permafrost; the better source usually being below the permafrost, where the yield is usually large and the water as a rule is of good appearance. Figure 1 is a diagram showing the occurrences of ground water in the permafrost region.

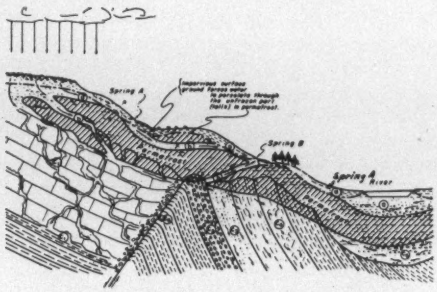

FIG. 1.—DIAGRAM SHOWING DIFFERENT OCCURRENCES OF GROUND-WATER IN THE PERMAFROST REGION.

This paper will describe ground-water supplies and treatment facilities developed for Ladd Air Force Base, located in the permafrost area near Fairbanks, and surface-water supply and treatment facilities for Fort Richardson, located near Anchorage, where the ground is not permanently frozen.

WATER SUPPLY—FAIRBANKS AREA

The water supplies for the air fields in the vicinity of Fairbanks are taken from wells 60 to 180 ft deep which, in the majority of cases, extend below permafrost. Since the ground temperature in the arctic and sub-arctic is close to freezing, the ground water likewise is only a few degrees above freezing. Temperatures of well waters in the Fairbanks area average about 35° F. during the summer months and vary little during the other seasons of the year. The water level of the wells at Ladd Air Force Base is 12 to 15 ft below the ground level and that at Eielson Air Force Base is but 6 to 8 ft below the ground level.

A chemical analysis of well waters from the Fairbanks area shows

iron to be present in quantities greater than the limits recommended by the drinking-water standards of the U. S. Public Health Service. We have noted that iron has been present usually in ground waters of permafrost areas with which we are familiar in Alaska and Canada. As expected, manganese always accompanies the iron. Table 1 gives a typical analysis of water from one of the most frequently used wells at Ladd AFB. It is a relatively hard water—about 160 ppm of hardness—most, if not all, being of a bicarbonate nature; the pH is near the neutral point, and the iron and manganese total more than 4.0 ppm. The turbidity of the water is zero upon being drawn from the well, but it increases upon standing. The iron content of the water in the wells in the Fairbanks area varies from 2.5 ppm to as much as 25.0 ppm of iron as Fe. No satisfactory correlation could be obtained between the depths of the waterbearing strata and the amount of iron in the water.

TABLE 1.—TYPICAL ANALYSIS OF WATER FROM WELL NO. 6—LADD AIR FORCE BASE

Temperature	35.5° F.	
Turbidity	0	
pH	7.15	
		ppm
Total solids		258
Alkalinity (phenolphthalein) as $CaCO_3$		0
Alkalinity (methyl orange) as $CaCO_3$		180
Total hardness (soap method) as $CaCO_3$		160
Calcium as Ca		58
Magnesium as Mg		3
Sulfates as SO_4		20
Phosphates as P_2O_5		9
Iron as Fe		3.5
Manganese as Mn		0.7

The well waters were acceptable bacteriologically.

The Department of the Army follows the recommendations for drinking-water standards adopted by the U. S. Public Health Service, which state that iron and manganese should not exceed 0.3 ppm. The Army further stipulates in its Engineering Manual that no treatment for the reduction of hardness is required unless the hardness of the water exceeds 250 ppm, except for laundry water and boiler water.

(It has been estimated, however, that for a civilian community, where the cost of treatment is borne by the consumer, it is more economical to remove hardness at a central treatment plant, when the hardness exceeds 100-125 ppm.)

The water-treatment problem at Ladd AFB resolved itself into one of removing iron and manganese from the water. It is known that, normally, the iron and manganese can be removed by a number of ways, the basic methods being:

(1) By aeration and the passage of water through coke beds (where the iron and manganese oxides produced and the iron and manganese bacteria deposited on the coke act to remove these metal compounds from the water), followed by settling and sand filtration.
(2) By coagulation at a high pH value, followed by filtration. Lime is an excellent coagulant in this method.
(3) By filtration through a base-exchange material adopted for the removal of iron and manganese.
(4) By the application of free-residual chlorination to a water, followed by settling (or by a contact period) and sand filtration. This method is ineffective on some water, but effective on others.

To determine which method would be most satisfactory from an operational and economical point of view, a pilot-plant water-testing laboratory was established at Ladd Air Force Base, including an aeration and coke-treatment pilot plant, and a base-exchange pilot plant. Other methods of iron and manganese removal were tried with the jar-test procedure. Tests were conducted during the summer of 1948. Figure 2 shows the inside of the pilot plant. The wooden barrel is a part of the aeration and coke pilot plant; the metal container on the left is a part of the base-exchange pilot plant.

Summarized briefly, the results obtained were as follows:

(1) Aerating the water and filtering it through coke removed only about 50% of the iron, unless the water was allowed to warm up during the settling period, in which case more iron was removed. Water was trickled through the coke, passed upward through the coke, and passed downward through the coke, which was submerged in the water. The method used in passing the water through the coke made no appreciable difference in the percentage of iron reduction.

(2) Lime, used as a coagulant to raise the pH of the water, removed the iron and manganese quite satisfactorily at a pH of about

FIG. 2.—INSIDE OF THE PILOT PLANT.

8.0 without adding appreciably to the hardness. Lime in sufficient quantities would remove the hardness in this water as well as the iron and manganese.

(3) The base-exchange method was successful in removing all the iron and manganese and it also removed all the hardness. Since the percentage of removal of the iron had to be so great, split treatment was not feasible.

(4) Chlorine in sufficient quantities to produce a 30-minute residual of 0.5 ppm caused the removal of iron and manganese to acceptable limits after filtration. Most of the removal took place in the filter.

Chemicals, such as lime and salts for regenerating the base-exchangers, have to be shipped to Alaska from the United States. The freight increases the costs of these chemicals some threefold and would make the treatment of the water expensive. In addition, large quantities of chemicals would have to be stored at the site to take care of any delay in the arrival of the chemicals. Chlorine, which is used in much smaller quantities than either lime or salt, can be stored much more conveniently, since it comes in steel cylinders. Moreover, post regulations at Ladd Air Force Base required that the residual chlorine in the water at all times be 0.4 ppm. The most desirable

method of treatment proved to be the removal of iron and manganese by the use of chlorine.

There are two populated areas at Ladd Air Force Base, separated by about two miles. Whereas in the temperate zone one treatment plant would serve both such areas, here the high cost of connecting the two areas by means of a heated water main made it more economical to build two treatment plants.

The treatment process consists of applying gaseous chlorine to the raw well water as it enters the treatment plant, slow mixing of the water to assure thorough contact, settling in a "contact" basin and thence passing the water through rapid sand filters. Storage is provided in a clear-well, whence the treated water is pumped into the distribution system via a pneumatic tank. The design capacities of the two treatment plants designed for ultimate construction at Ladd Air Force Base are 1.2 mgd and 1.8 mgd at average rate of flow. The more important features of the smaller plant are discussed below. All units except the filters are designed for three-fourths of the load. When required, increased facilities will be added.

Two slow-mixing units, with vertical mechanical stirrers for thoroughly mixing the chlorine with the raw water, are used. The detention time at the average rate of flow is 30 minutes. Piping is so arranged that the tanks can be operated in series or in parallel. Each tank is 12 ft square by 9 ft deep to the water line.

The settling tanks, which have the same 12-foot width as the mixing tanks, are each 50 ft long and have an average depth of 6 ft to the water level. To minimize short-circuiting as much as possible, the influent end of the tank is provided with a series of circular openings, so as to direct and spread the flow of water. No mechanical scraping devices will be used with the chlorine method of treatment, as would be necessary with lime treatment. These tanks may be operated either in series or in parallel. Our intent has been to make the mixing- and settling-tank facilities as flexible as practicable. The overflow rate is approximately 1,000 gal per sq ft per day and provides a detention time of 60 min. This overflow rate is based on the average rate of flow for ultimate design population, although initially sufficient tanks are provided for only three-fourths of the ultimate design population. Provision has been made for expansion when future growth of the post warrants.

The filter units have been designed for a filtering rate of 2 gal per min per sq ft at the average daily rate of flow, an additional allowance being made for wash-water requirements. Three filters have been used, each being 13′0″×13′0″ square. Cast-iron wash-water gutters and a perforated cast-iron underdrainage system have been provided. Each filter is provided with a rotary surface washer. The filters were made large enough to handle the ultimate design population.

Since Alaskan construction costs are high and an elevated storage tank would have to be heated, it has been more economical to provide wash-water pumps rather than elevated wash-water tanks. Each plant is provided with two 3,000-gpm pumps, designed to operate under a total dynamic head of 75 ft, one of each pair to serve as a standby unit. Water will be drawn from the clear-well for this purpose.

The clear-water storage was designed only large enough to handle the hourly variation in current domestic demand, and has a capacity of approximately 300,000 gal. Clear-water basins are located under the settling basins and would normally expand with them when necessary. It was felt that, with adequate pumping facilities, the natural ground-water storage was sufficient to supply the fire requirements.

In addition to the wells for domestic use, separate wells with pumps exclusively for fire use are provided, to pump chlorinated, but otherwise untreated, water directly into the mains. These pumps have dual drives and can be controlled either locally or at a central remote point. A surge tank is introduced into the line in each pump house, to prevent excessive water-hammer when these pumps are started or stopped. Two fire wells have been provided for the military area, each well being a 24-inch gravel-packed well, with pumping capacity rated to deliver 750 gpm at a gage pressure of 75 psi.

No elevated storage has been provided, because of the severe climatic conditions. Water is pumped directly from the clear-well into the 25,000-gallon pneumatic tank and thence discharged into the distribution system. The pneumatic tank is used for the control of surges as well as for pressure-control operations. The following pump capacities are provided: one at 0.5 mgd, one at 1.0 mgd, one at 1.5

mgd, and one standby at 3.0 mgd. All pumps are electric-motor-driven. In case of power failure, an emergency supply of chlorinated raw water can be obtained from the dual-drive equipment in the fire-well pumping stations. High-lift pumps in the treatment plants will be automatically controlled from the pneumatic tank in rate steps of 0.5 mgd. The maximum pressure in the tank will be 75 psi and the minimum 60 psi. All pumps are so placed as to have a flooded suction at all times.

Water Supply—Anchorage Area

Climatic conditions in the vicinity of Anchorage, which is about 250 miles southerly of Fairbanks, are not nearly as severe as those at Fairbanks; the weather can be likened to that of northern Maine. Seasonal frost penetrates the ground to depths of 7 to 9 ft and deep trenching is required for the water mains.

Ship Creek, which originates in the mountains east of Anchorage at about elev. 4,000, flows by Fort Richardson and Anchorage and empties into Knik Arm. It is a non-glacial stream, with yearly flow fluctuations of 20 to 1,500 cfs, and it provides the water requirements of Fort Richardson and the city of Anchorage. The water is relatively soft, about 65 ppm of hardness expressed as $CaCO_3$, with a pH of 7.6. The other chemical characteristics are within the limits established by the U. S. Public Health Service (see Table 2).

Table 2.—Typical Chemical Analysis of Water from Ship Creek

Turbidity	See Table 3	
pH	7.6	
		ppm
Total solids		102
Alkalinity (phenolphthalein) as $CaCO_3$		0
Alkalinity (methyl orange) as $CaCO_3$		65
Total hardness (soap method) as $CaCO_3$		65
Calcium as Ca		23.8
Magnesium as Mg		1.5
Sulfates as SO_4		12.0
Chlorides as Cl		10.6
Nitrates as NO_3		2.0
Silica as SiO_2		11.0
Phosphorus as P_2O_5		15.0
Iron as Fe		0.3

The watershed is uninhabited. Normally the water has no turbidity, but during the spring thaws and autumn rains the turbidity increases from below 10 ppm to over 200 ppm (see Table 3). Although the turbidity of the stream is below 10 ppm for the greatest part of the year, the turbidity during the other times makes the water objectionable for domestic use, and it was decided that treatment, which was started when Fort Richardson was first built, would be continued and improved.

TABLE 3.—MAGNITUDE AND FREQUENCY OF TURBIDITY OF WATER OF SHIP CREEK

Range in turbidity (ppm)	Number of days												Total days
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Year 1947													
0-10	31	26	19	23	23	29	31	31	24	29	23	31	320
11-20			1	7	2	1			2	1	2		16
21-40		1			3				1	1	2		8
41-100		1	5		3				3		2		14
101-200			3										3
Over 200			3								1		4
Maximum turbidity, 350 ppm on 20 March.													
Year 1948													
0-10	31	29	27	7	16	27	31	30	27	29	28	31	313
11-20				7	7	1		1	2	1	1		20
21-40			2	6	8	1				1	1		19
41-100			1	3		1			1				6
101-200			1	2									3
Over 200				5									5
Maximum turbidity, 375 ppm on 9 and 10 April.													

At the time the old water-treatment plant was built, a temporary dam and intake were built on Ship Creek, about 6½ miles east of Fort Richardson and about 3,000 ft from the treatment plant. This dam was a shallow, rock-filled, wooden-crib-type structure of a temporary nature and required constant maintenance and repair. Although the intake was heated, difficulties were encountered during the winter months in keeping the intake open, because of icing conditions.

To insure a safe and dependable water supply, a concrete gravity-type dam with intakes at two levels was designed. Two water-

supply intakes are to be installed, 20 and 10 ft below the spillway crest. We have provided compressed-air outlets around the intake racks and gates in the event that compressed air is needed to prevent icing.

The water-supply line from the intake to the water-treatment plant is a 30-inch cast-iron pipe, laid on a gravel bed and backfilled to a minimum cover of 5 ft.

The location of the proposed dam is in a narrow gorge, approximately 600 ft upstream from the existing dam and intake. The shape of the reservoir is narrow and the stream bed steep, so that the storage capacity per foot of dam height is small; the gross capacity of the reservoir is about 5 mil gal. The minimum flow of the stream was estimated to be such as to serve adequately the needs of the post and the city of Anchorage.

The data on rainfall and stream run-off in Alaska, like other sparsely inhabited areas, are inadequate. Weather conditions vary so between localities in Alaska that it is unsafe to attempt to fit the conditions of one locality with those of another. An estimate of future conditions is predicated on the wise choice of assumptions and correlating their findings with the limited observed data.

The watershed area of Ship Creek is partly wooded and contains some 92 sq mi. The timber line appears to be about 1,000 ft above the level of the spillway, and the terrain adjacent to the storage basin has moisture-retentive characteristics. From the records available, the greatest run-offs take place during the spring thaws and the autumn rains.

The average annual flood flow of Ship Creek appears to be in the order of 1,500 to 2,000 cfs, with 3,000 cfs occurring more infrequently. Although data in regard to past flood peaks are vague, a peak flow of 8,000 cfs is expected to be reached. This amount has been verified somewhat by high-water indications along Ship Creek, as well as our attempt to construct a synthetic unit hydrograph on known and assumed conditions.

Exploratory borings were made at the dam site, to determine foundation and abutment conditions. The bed of the stream and the side walls of the canyon were rock, identified as predominantly greenstone lava with an intermingling of greenstone tuff, nearly black in color. Figure 3 is a rendering of the dam and intake.

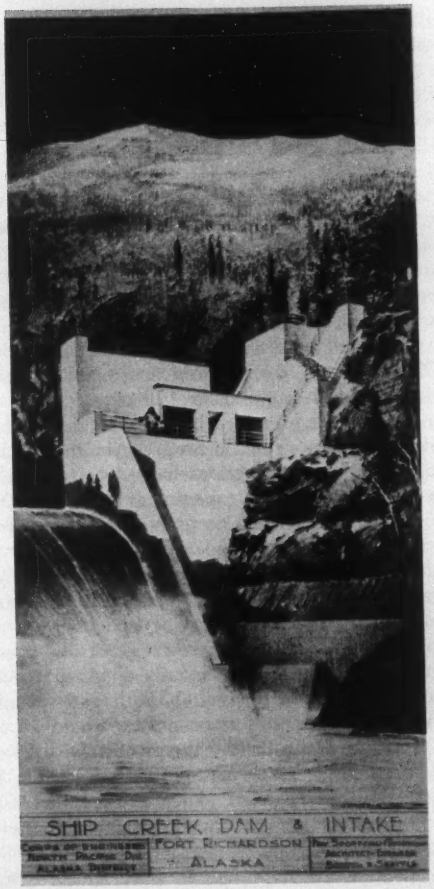

FIG. 3.

The spillway or overflow section of the dam is an ogee gravity type, designed to discharge 8,000 cfs under a head of 15 ft. The upstream face of the dam has been thickened, to assure stability under ice pressure of 20,000 lb per linear foot, the ice being 3 ft thick. The toe of the spillway section terminates in a curve, whose downstream face is parallel to the bed of the stream in preference to an upturned bucket.

The intake structure is adjacent to the spillway on the upstream face of the dam. It is of reinforced concrete construction, semicircular in shape, and is composed of a dry well and wet wells for intake at two levels, an operating floor, and a superstructure. The superstructure contains a manually operated jib crane for the removal of the equipment, gate stands for manually operating the interior intake gates, and a hot-air, oil-fired heater for heating the entire structure. Oil tanks have been placed in a small, separate, slightly heated building adjacent to the control house.

The two intakes are protected by semi-circular coarse racks and are equipped with sluice gates, located within the intake structure. Two removable screens of ½-inch mesh are located within the intake structure, so as to screen water taken at either level. The wet wells are so arranged that either intake gate or screen can be repaired and cleaned while the other is in operation.

The sluicing conduits, passing through the dry well of the intake structure, are so placed as to be able to carry silt away from the two intakes. The investigation of the cost of various types of gates has resulted in choosing a 3-foot-diameter, electrically operated pivot-type valve in conjunction with a manually operated, 3-foot-diameter, circular sluice gate, located upstream. Both gates would normally be closed. When sluicing, the upstream gate would be opened wide and the flow would be controlled by the pivot valve. These gates are protected by a bar trash rack. Grooves are placed in the influent flume, to facilitate the repair of sluice gates if necessary. These gates can also be used to limit the flow of water over the dam during periods of flood flows.

The old water-treatment plant at Fort Richardson, built just before our entry into World War II, is of a temporary nature. It is of all-wood construction, with circular, concentric mixing and settling

tanks, and circular rapid-sand filters. Coagulation is obtained by using lime and alum. Since the mixing is poor and settling is not complete, the rapid-sand filters are overloaded and clog quickly. Because of limited funds, it is proposed to build a new treatment plant in two stages. The first stage will be the construction of permanent-type mixing and settling basins, large enough to handle the filtering capacity of the existing filters—3.0 mgd at average daily flow rates —with provisions for future extension of mixing and settling tanks and new rapid-sand filters. The existing rapid-sand filters, while of a temporary nature, are considered adequate to meet the present requirements of the post when acting in conjunction with the more efficient mixing-and-settling-tank installations in the new treatment plant.

The existing clear-well and chlorinating equipment will be used in conjunction with the new construction. The design of the initial construction will provide for economical enlargement at some later date.

Experience in the operation of the present filter plant indicates that a satisfactory floc can be obtained with the use of alum and lime. The proposed first stages of new construction would consist of rapid mixers, slow-mix basins, settling basins and chemical feeders, and storage room.

Since all treatment facilities in this part of Alaska must be covered to prevent their freezing, it was decided to make the settling tanks a two-story affair for economic reasons. The plant has been designed so that all units are duplicated, in order to allow the operator greater flexibility in operation and for plant-scale experimentation. See Figure 4 for a rendering of the water-treatment plant.

Immediately after alum and lime are added, the mixture is stirred rapidly in a vertical rapid-mix basin with mechanical stirrers. The influent enters the bottom and leaves at the top. Mixing time is one minute at average rate of flow. The size of the unit, one for each mixing tank, is 3′ 6″ x 3′ 6″ x 13′6″.

The slow-mix basins, or flocculation basins, are an integral part of the settling basins. The depth is therefore relatively shallow and the width is twice the depth, allowing the use of two parallel rows of paddles with successive blades in each row normal to preceding blades,

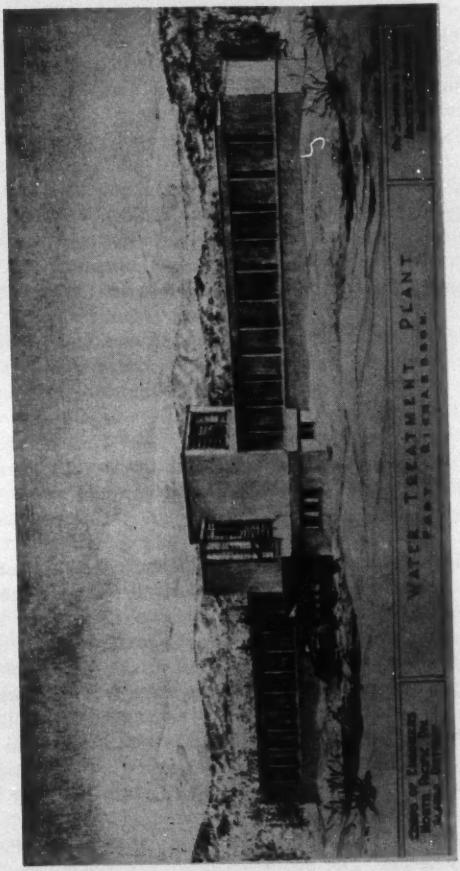

FIG. 4.

and opposite blades in the parallel rows normal to each other. The detention time for average rate of flow is 40 min. A baffle with orifices has been placed at the influent end of the flocculating basin and also at the effluent end. The baffle was placed at the effluent end to diminish short-circuiting in the adjacent settling basin. The size of the mixing basin is 8′ x 16′ x 42′.

Settling of a floc is primarily a function of the specific gravity of the floc, the characteristics of the floc, the viscosity of the water, and the hydraulic characteristics of the settling basin. Everything else being equal, the removal of particles in a settling basin is a function of the surface area and independent of the depth. To improve the hydraulic characteristics of the settling basin by hindering short-circuiting, the tank should be long with respect to its width.

The settling tank, as stated above, is a two-story affair, the top story being 16 ft wide by 58 ft long and the bottom story, 16 ft wide by 100 ft long. The water enters the settling tank from the mixing tank, flows through the top story, drops down and passes through the bottom tanks. The average path of water travels, therefore, 158 ft. Full-width mechanical scrapers are provided in the upper story. The bottom of the lower story is sloped and the mechanical scrapers are placed in the center section only. The average depth of each story is 8′ 0″. Although a depth of 5 ft would have sufficed, to allow for the installation of the commercial mechanical scrapers, the added depth was for the storage of sludge, if desired. The overflow rate varies from 700 to 1,000 gal per sq ft per day for average to maximum rates of flows. The detention time at average rate of flow is approximately 2½ hours.

The chemical room is in the central section, above the operating floor. The supply of chemical is conveyed there by means of an inside elevator. Four chemical feeders are provided for the application of lime and alum. This provides a standby feeder for each coagulant and, if desired, permits flexibility of operation. The coagulants can be fed into the main incoming line or into each mixing-basin influent line, so that different doses of coagulant can be used for each basin, if large-scale trial tests are desired.

The ground floor of the central section contains the office, a chemical and bacteriological laboratory, and the locker room.

It has been brought out that the new additions will serve only the immediate future and an extension will have to be made at some future time. It is hoped that by that time the operational records on this design will be such as to guide the design of the future extension.

Summary

In the design and construction of water facilities in Alaska, climatic and geological conditions are of unusual importance.

In a permafrost area, such as the Fairbanks area, the safest kind of water supply is a ground-water supply, obtained below or between permafrost layers. Water is distributed by pipe lines carried in utilidors, or boxes which carry all utility piping, including sewer and steam pipes. Treatment of the water should be no more than enough to satisfy the requirements for a potable water, for the treatment facilities must be completely housed.

In areas where permafrost does not exist and where the climatic conditions are more moderate, such as the Anchorage area, surface supplies may be used advantageously.

Descriptions have been given of two water supplies, one a ground-water supply in a permafrost area and the other a surface supply in an area having a moderate climate.

Acknowledgment

The writers wish to thank their associates for the aid and advice given them during the design of these water-supply facilities in Alaska. We should like to thank, especially, Mr. Murray H. Mellish, head of the Sanitary Department for the Alaskan Facilities, of Fay, Spofford & Thorndike.

EXPERIMENTAL BREAK-POINT CHLORINATION AND ANTI-CORROSION TREATMENT AT MAYNARD, MASSACHUSETTS

BY WERNER N. GRUNE*

[*Read at Chemists' Round Table, March 16, 1950.*]

DURING the late winter and early spring of 1948 certain pilot-plant studies were made at the White Pond Water Works, supplying the town of Maynard, Mass. This paper will relate the results of these studies. It consists of extracts from a thesis submitted at the Harvard Graduate School of Engineering. The thesis, entitled "Break-Point Chlorination and Anti-Corrosion Treatment", was submitted as a partial requirement of the course on the Theory of Water and Sewage Treatment.

The principles of corrosion and chlorination practices are old and time-proven and need no elaboration. Therefore only a minimum of previously published information is here included for the sake of ready reference, coherence, and understanding of the material presented. The application of the techniques and principles to be discussed in their peculiar adaptation and combination to perform a special duty is the main object of this paper. The subject deals with the practical application of fundamental knowledge, demonstrating the engineering approach pooled together for the solution of very similar conditions elsewhere which have annoyed water-works officials (and consumers!), especially in New England, for many years. This combination of principles, when properly applied, can do a man's job and eliminate the problems.

The repetition of fruitless details and the review of well established facts are touched upon, because it is felt that a brief introduction of the factors causing and contributing to electrochemical corrosion is in order, for the sake of continuity and comprehensiveness.

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The Economic Significance of Corrosion

An accurate estimate of the loss resulting from corrosion of iron and steel is, of course, out of the question. Various estimates made several years ago place the economic loss due to corrosion of ferrous metal pipe alone at somewhere between 50 and 250 million dollars annually. This figure is not purely derived from repairs and replacements, but also includes: loss of water through leaks; the necessity for larger pipes, when it is known that the carrying capacity will be greatly reduced by the formation of iron rust, especially tuberculation; repairs by the water department; repairs by the consumer; fire losses due to inadequate water pressure, caused by a partial stoppage of the mains; staining of bathroom fixtures and household appliances; staining of textiles, laundry and paper pulp, off-color dye shades, leather, and many more.

Frank N. Speller (1) states that "because of inadequate protection, the annual replacement from corrosion, on the average, may reach as much as 2 per cent of the total tonnage in use. Probably no other source of waste, except that affecting human life, is of greater concern to all."

Control of corrosion has not always been recognized as of sanitary significance. In the attempt to furnish cities and towns with clear, pure and palatable waters, in many instances corrosion troubles have been increased, such as those produced from alum coagulation and adjuncts of water-softening processes, besides troubles from those waters that are corrosive by nature. In order to know best how to treat water against corrosion, a brief outline of the theory is presented.

The Theory of Corrosion

The corrosiveness of water has popularly been held to be due to the carbon-dioxide content of the water. This is true only in so far as the CO_2 influences the pH value and prevents the deposition of a mineral film on the surface of the metal or pipe. Fundamentally corrosion is due to the exposed metal in the water exhibiting a distinct tendency to go into solution. The rate of solution may be expressed as inversely proportional to the alkalinity and pH of the water; *i.e.* corrosion is less with higher alkalinities and pH values. The metal dissolves in the form of positive metallic ions, the charge being taken

from the hydrogen ions in the water—polarization. This leads to the deposition of a polarizing film of gaseous or molecular hydrogen on the metal surfaces, which in turn prevents further electrochemical action, unless the hydrogen is removed by the scouring action of the flowing water or oxidized by the oxygen dissolved (at pH above 5), or the hydrogen is evolved as gas in very acid solutions (pH below 5). These steps are summarized in Table 1.

TABLE 1.—THEORY OF CORROSION

(1) Metallic ions going into solution = Anodic Area

$$Fe + 2e = Fe^{++}$$

(2) Hydrogen giving up electrons and polarizing, *i.e.* "plating out" at the Cathodic Area

$$2H^{+} = 2e + 2H \text{ (or } H_2)$$

(3) Dissolved oxygen from natural waters reacts with the hydrogen to form water molecules, *i.e.* "depolarization" of 2H, and thus corrosion is continuously furthered and enhanced:

$$2H_2 + O_2 = 2H_2O$$

(4) Ferrous iron is oxidized to the ferric state by dissolved oxygen and eventually is precipitated as rust:

(4a) $2Fe^{++} + \frac{1}{2}O_2 + H_2O + 4OH^{-} = 2Fe(OH)_3$ ($K_{SP.} = 1.1\times10^{-36}$)

(4b) $2Fe(OH)_3 + nH_2O = Fe_2O_3(n+2)H_2O$ (red iron rust!)

(5) Reaction of ferrous iron with water to form an intermediate product, ferrous hydroxide:

$$Fe^{++} + 2H_2O = Fe(OH)_2 + 2H \text{ (hydrogen film)}$$

(6) As quickly as the $Fe(OH)_2$ is formed it reacts with CO_2, if present, to form soluble ferrous bicarbonate:

$$Fe(OH)_2 + 2H_2O + 2CO_2 = Fe^{++} + 2(HCO_3^{-}) + 2H_2O$$

(7) The product form is soluble, thus not remaining attached to the pipe interior. The soluble $Fe(HCO_3)_2$ is oxidized by the dissolved oxygen in the water, to form ferric hydroxide and to liberate CO_2:

$$4Fe^{++} + 4(HCO_3^{-}) + 10H_2O + O_2 = 4Fe(OH)_3 + 8H_2 + 8CO_2$$

This reaction occurring throughout the water and not on the pipe surface only, ferric hydroxide is precipitated as suspended particles in the water (*red water*) without the formation of any protective film.

Equations (5), (6) and (7) refer to waters of low pH containing CO_2. Conversely, reactions that occur in alkaline waters of high pH and in the absence of CO_2, but in the presence of dissolved oxygen, are:

(8) The ferrous ion at moment of liberation from the surface reacts with the OH^{-} ion present in alkaline waters, forming an insoluble film:

$$Fe^{++} + 2OH^{-} = Fe(OH)_2 \ (K_{SP.} = 1.6\times10^{-14})$$

(8a) This can also be represented as ferrous oxide and water:

$$Fe(OH)_2 = FeO + H_2O$$

(9) If dissolved oxygen is present in the water, it will oxidize this film of $Fe(OH)_2$ to form the more insoluble film of ferric hydroxide:

$$2\,(FeO + H_2O) + \tfrac{1}{2}\,O_2 = Fe_2O_3 + 2\,H_2O = 2\,Fe(OH)_3$$

Thus with suitable alkalinity and pH of water, insoluble films are formed on the pipe surface, whether dissolved oxygen is present or not. The conditions favorable for these reactions are closely related to the conditions governing the precipitation of $CaCO_3$. In fact, the ferrous and ferric hydroxides form films which are somewhat porous and do not protect the pipe surface, unless $CaCO_3$ is co-precipitated, forming part of the film. The latter part of this paper deals further with the $CaCO_3$ film, the application of the Langelier expression and results obtained at Maynard.

In addition to the reactions just discussed it should be emphasized here that no single factor alone controls corrosion. It is a combination of many factors and environment which determines whether or not corrosion is a problem. To indicate some of the complexity of this behavior, ten different factors influencing corrosion may be mentioned:

1. Oxidation potential
2. Overvoltage of hydrogen on metals
3. Homogeneity of surface
4. Inherent ability of metal to form protective films
5. Hydrogen-ion concentration
6. Oxygen concentration
7. Bacterial corrosion
8. Formation of films by liquid
9. The effect of temperature
10. Corrosion fatigue or stress cycles.

The Role of Carbon Dioxide

The effect CO_2 has on corrosion was overemphasized in the past, often to the near exclusion of many other vital factors. CO_2 is present in one form or another in nearly all natural waters, both surface and ground waters. The amount of carbon dioxide in that portion of the total H_2CO_3 which ionizes into H^+ and HCO_3^- ions is called "aggressive" CO_2, because it produces hydrogen ions in a given quantity

of water, increasing the hydrogen-ion concentration. The term "aggressive" was used to indicate that whenever the hydrogen-ion concentration was increased, the rate of corrosion was also increased. As is known today, *the increase in hydrogen-ion concentration has no effect upon the rate of corrosion of iron, until the pH of the water is below 5.5* (2).

It is evident that free CO_2 in water produces two important results:

(1) *It prevents deposition of $CaCO_3$ as a coating on the pipes* (by slowly forming carbonic acid).
(2) It may produce hydrogen ions, thus increasing the hydrogen-ion concentration (by ionization of free carbonic acid).

Since free CO_2 dissolved in water increases the number of hydrogen ions present, it accelerates the solution of iron by forming more H^+ ions to give up their charges to the iron and permit more Fe ions to unite with any slightly dissolved OH^- ions in the water, forming the initial $Fe(OH)_2$. This possibility of CO_2 accelerating corrosion of iron by increasing the hydrogen-ion concentration is described because it was very generally held by water-works people as readily explaining the corrosiveness of waters.

The rate of corrosion is ordinarily governed by the rate at which reaction (3) proceeds. Wilson (3) has shown that dissolved oxygen is the governing factor at pH 5 to pH 11, which covers practically the entire range ordinarily found in natural or treated surface waters. Below pH 5.0 the hydrogen ion concentration has a marked effect.

The role of carbon dioxide in corrosion of pipes may be summed up as follows (2):

1. When the total CO_2 in water is just sufficient to react with the carbonates present to form bicarbonates, maintaining equilibrium, the hydrogen-ion concentration is not affected. The carbonates are prevented from forming a thin film on the pipe. The pipe wall is, therefore, unprotected from the corrosive action expressed by equations (2) and (3).
2. When the total CO_2 is greater than that required to keep the carbonates in solution, the same conditions hold and, in addition,

free CO_2 is available to form carbonic acid. When the pH is above 8.3, this carbonic acid will not ionize and therefore is not "aggressive" in most natural waters. When the pH is less than 8.3, the carbonic acid ionizes to H^+ and HCO_3^- ions, increasing the hydrogen-ion concentration of the water. When the pH gets as low as 5.5, or thereabouts, the increased hydrogen-ion concentration due to CO_2 accelerates the rate of corrosion and nearly all the free CO_2 is "aggressive". Under this condition, the acidity of the water is increased and the effectiveness of any protective coating of rust is greatly reduced.

3. When water is heated, the bicarbonates are destroyed, increasing the CO_2, which may, and usually does, become "aggressive". This explains in part the corrosiveness in hot-water pipes.
4. The free CO_2 may dissolve iron directly to form ferrous carbonate, which is later oxidized to form the ferrous and ferric hydroxide or rust. See equations (6) and (7).

The reduction of free CO_2 in water, therefore, tends to prevent corrosion chiefly by allowing a protective film of $CaCO_3$ to form, if such treatment is initiated, and by rendering the initial rust film more adhesive and thus of greater protectiveness. In water of pH greater than 7.5, the $CaCO_3$-rust protective coating is usually efficient in preventing further rapid corrosion. With some waters the pH must be carried to 8 or even 9 and above before corrosion troubles cease, at least for an interim period, after which some reduction in the chemicals fed and the pH value can be practiced.

There are two further types of corrosion which often plague water-works officials: galvanic corrosion, where two or more dissimilar metals are involved and potentials set up, and, secondly, stray-current corrosion. Both of these are not the subject of this discussion and therefore are not treated any further.

Mitigation or Correction of Corrosion

Six broad classifications of methods which have been applied with more or less success in the past can be considered. These are briefly:

1. The use of non-metallic pipes.

2. The use of metallic pipes with non-metallic linings and coatings.
3. The selection of metals resistant of corrosion.
4. The use of protective metal coatings on ferrous pipe.
5. Natural protective coatings.
6. Chemical treatment or conditioning.

Only chemical treatment is to be examined a little more closely. Red-water troubles in a distribution system can be prevented by adjusting the chemical balance of the water. Water may be treated so that an impervious film will be deposited over all iron surfaces with which it comes in contact. In this manner iron surfaces may be protected against the dissolving action of water. This method is of greatest importance, since many of our pipes have no man-made protection, such as coatings, and it seems to be the cheapest, wherever economically and practically feasible, to get at the root of the evil, *i.e.*, by chemical treatment of the water, removing all corrosive tendencies. (This will be accomplished when the concentration of calcium ions times the concentration of carbonate ions exceeds the solubility product of $CaCO_3$; *i.e.*, $(Ca^{++})\ (CO_3^{=}) \geqslant K_{SP}$.) This may prove the most efficient, cheapest and most reliable method in the long run.

Water that is supersaturated with $CaCO_3$ will quickly deposit a coating or film (also called an "egg-shell layer"), because in the process of corrosion the CO_2 is taken from the water. The solubility of $CaCO_3$ in natural waters is directly related to the CO_2 content; therefore, if some of the CO_2 is absorbed, the nearly saturated water becomes saturated, or perhaps supersaturated. When this point is reached, deposition of $CaCO_3$ begins ($CaCO_3$ is only soluble to the extent of 13 ppm in natural waters without the presence of CO_2) and the corroding iron becomes coated with a protective film of $CaCO_3$. The treatment to $CaCO_3$ saturation is often described as removal of CO_2, but this is not the most important feature. The action is by the deposition of an incipient film of $CaCO_3$ or other normal carbonates, secondarily by suppression of H^+ ions. Water that is under-saturated with $CaCO_3$ will dissolve $CaCO_3$ film already formed. Whether or not water is in chemical balance to $CaCO_3$ can be easily and quickly determined—*i.e.*, to determine whether or not the water is saturated,

supersaturated or undersaturated after the $CaCO_3$ and pH adjustments have been made. This was done formerly by the marble test, also variously known as the "calcium carbonate chemical balance" or "stability test," but has in recent years been placed on a direct analytical basis by the Langelier pH_S formulation, involving much less laboratory work. If the analysis shows that the water is undersaturated, then it is necessary, if red-water troubles are to be prevented, to build up the $CaCO_3$ content. This can be accomplished by adding lime to the water; or, if the hardness should not be increased and sufficient Ca^{++} ions are present, a combination of soda ash and lime might be tried, or, if the water contains some calcium sulfate, soda ash can be added and the results will be satisfactory. Soda ash reacts with $CaSO_4$ to form $CaCO_3$. It may also be convenient to build up the calcium-carbonate content by adding some hard water.

(I) *Alkali Treatment.*—If an alkali such as lime, soda ash or sodium hydroxide is added to water containing free CO_2, the free CO_2 is absorbed and a bicarbonate is formed:

(1) $$Ca(OH)_2 + 2\,H_2CO_3 = Ca\,(HCO_3)_2 + 2\,H_2O$$

(2) $$Na_2CO_3 + H_2CO_3 = 2\,Na\,(HCO_3)$$

(3) $$NaOH + H_2CO_3 = NaHCO_3 + H_2O$$

This treatment will prevent corrosion by free carbon dioxide, but this is not the most important feature. It will not prevent corrosion of pipe lines from the other causes heretofore mentioned. To do this it is necessary to add lime in *excess* of the amount necessary to absorb the free CO_2. This treatment forms normal carbonates, which are insoluble and are deposited on the pipe to form a protective coating [$Mg(OH)_2$ for magnesium]:

(4) $$Ca(OH)_2 + H_2CO_3 = CaCO_3 + 2\,H_2O,$$

i.e., theoretically *twice* as much hydrated lime is needed to *precipitate* $CaCO_3$ [compare reactions (1) and (4)].

In order to summarize and to indicate what the mechanism involved is, consider natural water that contains calcium ions (Ca^{++}), bicarbonate ions (HCO_3^-) and free CO_2. The bicarbonate is converted to the normal carbonate by the addition of lime, Na_2CO_3 or NaOH, and the proper conditions for the $CaCO_3$ solubility product to be exceeded are established.

Consider a typical New England water, *i.e.* low in calcium, low in bicarbonates and containing CO_2. Adding $Ca(OH)_2$, we increase the concentration of the calcium ions, the bicarbonates and the OH^- ions combining to give us normal carbonate ions ($CO_3^=$) and water, and therefore a *double effect* is brought about. This means that lime is excellent for the local water supplies, in so far as reaching the $CaCO_3$ saturation point is concerned.

If both lime and soda ash are added in the proper proportion, the reactions may proceed as follows:

$$Ca(OH)_2 + 2\,H_2CO_3 = Ca\,(HCO_3)_2 + 2\,H_2O,$$

equation (1) for the production of the calcium bicarbonate. The bicarbonate may then react with the soda ash as shown:

(5) $$Ca(HCO_3)_2 + Na_2CO_3 = CaCO_3 + 2\,NaHCO_3$$

With the protective coating once formed, it is only necessary to maintain the water at the point of calcium-carbonate saturation to prevent corrosion. Baylis (4) shows that the approximate solubility equilibrium of $CaCO_3$ varies from about 15 ppm to more than 350 ppm, corresponding to a pH of 9.3 and 6.8, respectively.

According to the 1940 A.W.W.A. Manual (5), "lime should be added to water with less than 25 ppm of $CaCO_3$ to produce the desired alkalinity. To other waters either lime or soda ash may be added. Lime dosages vary, but in general 8 to 10 pounds of lime per m.g. of water treated are required for each ppm of free CO_2 present in the water."

According to Charles R. Cox of the N. Y. State Department of Health (6): "Practically speaking, waters having a carbon dioxide content below about 5 ppm and an initial alkalinity less than about 10 ppm and which must be so treated as to provide a final alkalinity above about 35 ppm *should* be treated with *both* lime and soda ash. The relative lime and soda ash doses vary with different waters and must be computed, but an approximate guide would be to use a mixture of 80% lime and 20% soda ash until the correct ratio can be determined by experience. This mixture of the dry materials should be fed with a dry feeder in trial doses to the supply being treated until the resulting alkalinity equals that indicated to be necessary by the marble test or as calculated by the Langelier formulation."

(II) *Use of Soda Ash.*—Soda ash may be used to remove CO_2 and increase the pH value and the alkalinity of the water. Soda ash alone, however, cannot be used in the treatment of waters having $CaCO_3$ alkalinity less than about 35 ppm, because such soft waters do not contain sufficient calcium generally to form the required $CaCO_3$ film. In other words, waters having hardness less than about 35 ppm *must* be treated with lime (or at least some proportion of lime to soda ash) for corrosion prevention, rather than soda ash alone. On the other hand, waters with a hardness in excess of 35 ppm and yet having sufficient CO_2 to be corrosive may be treated with soda ash in a satisfactory manner. Furthermore, 1 g.p.g. of 98% pure soda ash removes only 7.06 ppm of CO_2, rather than 9.65 ppm, as are removed with lime. One ppm soda ash increases the alkalinity only 0.92 ppm. One ppm of lime increases the alkalinity 1.35 ppm approximately (depending on the purity).

Soda-ash treatment costs about four times that of lime and yet it is not as effective with soft waters. Soda ash, however, is very soluble and may be readily applied through the use of either solution-feed or dry-feed equipment, in contrast to lime feed. Therefore, soda ash is especially suited to the treatment of small supplies having a hardness in excess of about 35 ppm, where ease of application of the chemical more than compensates for its higher cost. The constant stirring and supervision, to keep a solution of lime and water in suspension, and the sludge problem are to be considered; therefore, a dry feed is much to be recommended, when either lime or a combination of lime and soda ash is used. Another advantage (which may sometimes be a disadvantage, as has been already mentioned), is that with the soda ash no additional hardness is created. This may be very important, as will be seen in the case of the Maynard water supply, where the hardness may be increased approximately 150%, due to the use of straight lime. This is a drawback in the use of lime, when water is so extremely soft and the people in the community, as well as industry, are naturally accustomed to it.

(III) *Use of Caustic Soda.*—Chemically, sodium hydroxide would be better than soda ash, but practically it would prove a troublesome substance to administer. It may be used for the correction of pH without any increase in the hardness. The use is un-

economical for public water supplies, principally because of the relatively high cost, compared with that of lime.

(IV) *Aeration as a Method of Mitigating Corrosion.* — The quantity of CO_2 held in solution by water depends upon the amount present in the air and the opportunity that the water has of coming into contact with the air—*i.e.*, it varies according to Henry's Law.

The amounts commonly present in waters are in excess of saturation—about 1 ppm under ordinary conditions—so that, if the water be exposed to the air (in thin films), a natural reduction of the dissolved CO_2 will occur. However, the concentration of CO_2 must be sufficiently above saturation to provide enough driving force for CO_2 removal. Baylis (4) mentioned 10 ppm as the lower economical limit. Its neutralization with lime would be expensive and would increase the hardness of the water by a considerable amount.

Aeration is a time-honored method of CO_2 removal, but aeration adds dissolved oxygen, which plays an all-important part in corrosion. Hence, it cannot be considered by itself as a complete remedy for corrosion.

At West Palm Beach (7), with a water of low alkalinity and high color, the alum dosage required liberates about 24 ppm of CO_2. Aeration, after coagulation, reduced the CO_2 content to 8 ppm; a second aeration after filtration reduced the CO_2 content to 5 ppm. The CO_2 content of the delivered water varied from 2 to 6 ppm and the pH from 6.2 to 6.8. Even these small amounts caused severe corrosion. Lime, added to the filtered water to increase the pH to 9.0, removed all CO_2, made for $CaCO_3$ deposition and stopped the trouble.

Grimley (8) described the correction of red-water troubles with an acid water at Irondale, Ala. The raw water had a pH of less than 5.2, total alkalinity of 8 ppm, and a CO_2 content of 46 ppm. Aeration of the water increased the pH from 5.2 to 6.5. This gain in pH represents a theoretical reduction in CO_2 from 40 ppm to 5 ppm.

It would be possible to combine aeration by fountains or sprays with the use of lime or soda ash, aeration being utilized to remove the greater part of the CO_2 and the small amount left being neutralized by chemical means. The initial amount dissolved in the water, of course, is a governing factor. The alternative proposition would be to prolong the exposure of the water to the air and thus reduce the CO_2

to the saturation value. This would not remove all the CO_2, but the dissolved-oxygen content could easily become so high that it might very well more than offset what was gained by the loss in CO_2. Powell & Bacon (9) in their paper speak about creation of a 28.5-in. (Hg) vacuum in a de-aeration chamber, to reduce the dissolved-oxygen content. However, this is economically not yet feasible for most water-work installations.

Control and Destruction of Organic Life and Iron Bacteria as an Aid in Corrosion Control

So far, only the mechanism of corrosion and the prevention thereof have been mentioned. The conclusions reached are that practical attempts to control corrosion by the treatment of water are principally confined to (1) the control of the carbonate balance and (2) to the removal of dissolved gases (including H_2S).

It is astounding how devoid the literature is of definite findings of organic and bacterial action, including the effect iron bacteria have on corrosion. Bacterial action does contribute to the corrosion of iron, as has been demonstrated by the fact that the diminution of biological activity will diminish corrosion.

The addition of chlorine to water will diminish its bacterial content and in this way aid greatly in the control of iron bacteria and corrosion. However, the presence of organic matter may not only exhaust the *ordinary* chlorine dosages, but also furnish food for after-growths of the bacteria, some of which may consume dissolved iron, increase the rate of corrosion of the metal, and encourage tuberculation and "red-water" conditions. The addition of ammonia with the chlorine was at one time thought to be the answer. It was then theorized that the addition of ammonia with the chlorine would retard the exhaustion of the chlorine, so that it might be carried into remote parts of the distribution system, where its bactericidal effects would endure longer. Methods and principles in the addition of ammonia for corrosion control were practiced in the same manner as in its addition for taste and odor control. In a few instances it was found that the use of ammonia did actually aggravate the difficulties from corrosion in certain parts of the distribution system, probably due to two causes: (1) due to the fact that, when the chlorine is finally

exhausted, the remaining ammonia furnishes food for the undesirable aftergrowths; and (2) the low disinfecting power that chloramines actually have was not generally recognized then. Today the advantages that can be gained from super-chlorination and break-point chlorination have been recognized and are accepted. It is this method of chlorine application that is promising in finally getting the job done.

Before going into detail on the use of chlorine application, a brief consideration of the organisms involved in the corrosion of iron pipes, such as iron bacteria, is in order.

The "Sheath-Forming" and "Stalked" Bacteria

The so-called "sheath-forming bacteria" are, in many respects, among the most interesting organisms. They are grouped together in the order of Chlamydobacteriales (10) because of the presence of a definite soft and slimy sheath, in which the bacteria enclose themselves.

The Chlamydobacteriales (chlamydo = sheath-forming) are unique among the class of Schizomycetes in the possession, by most of the species, of an extraordinary capacity for abstracting iron from feruginous waters and depositing it in their outer sheath, where it quickly oxidizes to ferric hydroxide. It may be that not all of the Chlamydobacteriales are true iron bacteria, for *Sphaerotilis* is said not to deposit iron in its sheath and is mainly a sewer organism. Although the iron bacteria are the most outstanding among the organisms which accumulate certain elements or compounds on their exterior, they are by no means the only ones that do this. The diatoms, which surround themselves with silica so that cell growth is eventually hampered, are suggestive of iron bacteria which encumber themselves with iron or manganese. Certain of the algae, protozoans and molds have also been shown to collect iron. *The utilization of iron, or any other element, in the synthesis of protoplasm must, of course, be carefully distinguished from its mere deposition on the exterior membranes.* Among the most interesting considerations related to these bacteria are their remarkable physiological properties, their role as geological agents and their part in interfering with man's attempts to provide himself with pure water. None are pathogenic, but several, as *Sphaerotilis* and *Crenothrix,* cause difficulties in water

supplies. Bergey's Manual lists four genera in this family—namely, *Leptothrix, Crenothrix, Sphaerotilis* (or *Cladothrix*) and *Clonothrix.*

Leptothrix ochracea, the best known of this genus, is world-wide in distribution. It is found in rivers, lakes, ponds and swamp waters which contain iron in chemical combination with organic matter—*i.e.,* decaying plants, for example. The reddish-colored slimes found in the beds of iron-bearing waters nearly always owe their origin to the deposition of $Fe(OH)_3$ or some hydrated ferric oxide in the outer membranes of the long filaments, formed by iron bacteria growing on the stream bottom. Living iron bacteria, however, are seldom found in such iron deposits, since the incrustation of the membrane with the iron occurs only in maturing filaments and eventually, since it oxidizes to $Fe(OH)_3$ and becomes hard and inelastic, interferes with their further reproduction. *Leptothrix* multiplies only in the presence of sunlight. From this fact one might infer the presence of some photosynthetic pigment, although none has been demonstrated.

Genus Crenothrix

The three genera to be described have an entirely different structure and mode of reproduction from *Leptothrix.* A description of one species, *Crenothrix polyspora,* will serve to illustrate features common to the other two genera, *Sphaerotilis* and *Clonothrix.*

The *Crenothrix* (Figure 1) starts life as a single, nearly spherical cell, which divides by fission and forms a chain, much as do the *Streptococci,* but differing in that the cells elongate as they divide. The topmost cells are continuously being pushed out of the mouth of the sheath by the growing cells below. Under certain conditions of nutrition, such as an abundance of iron-bearing organic matter, small numbers of competing organisms, and plenty of oxygen and warmth, *Crenothrix* goes into a perfect orgy of reproduction. Under such conditions of growth *Crenothrix* may, in less than a week, change a large body of drinking water, initially sparkling and clear, to a lake of red-brown fluid. The saprophytic bacteria, which cause decomposition of the dead *Crenothrix,* increase in numbers so that the reports of bacteriological laboratories to the engineer, on the number of bacteria present in the water, become very discouraging.

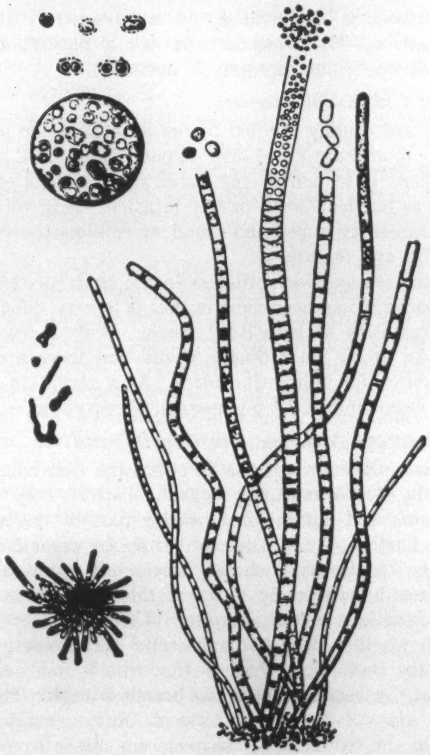

FIG. 1.—CRENOTHRIX. SKETCH OF PLANT IN VARIOUS STAGES OF DEVELOPMENT [AFTER C. R. COX (6)].

Relationship of Chlamydobacteriales to Other Classes of Organisms

The order as a whole seems to be more bacterial than mold-like or alga-like. It is entirely aquatic. The organisms have certain mold-like characteristics in their reproduction and structure, but on the

whole they behave as bacillus-like cells and frequently are motile by means of flagella. The iron bacteria are a borderline case with respect to autotrophic or saprophytic bacteria.

Physiology of Chlamydobacteriales

Cultures are usually studied in the natural water in which the organisms occur and are necessarily impure. The usual procedure in such cultivations is to add to the water small quantities of organic matter, such as nutrient broth or hay infusion, along with iron salts. The colonies are rusty-brown and round, resembling those of ordinary bacteria in size and texture.

One of the reasons why progress in the study of the physiology of the iron bacteria has been slow is that it is very difficult to cultivate these organisms in laboratory media. With a few exceptions, they cannot be grown on ordinary media and there are no known simple procedures for cultivating them. As a result, in most cases, studies have been limited to microscopic observations.

Relation of Iron and Manganese to Iron Bacteria

Studies have brought out the fact that the iron bacteria have a peculiar affinity for iron-bearing organic matter; they may utilize only the *organic* and not the iron-bearing part of the molecules of such matter. Further, the iron released from the organic combination is deposited on the bacterial sheath, where it is eventually oxidized to ferric hydroxide and finally forms so thick a crust as to end the reproductive functions of the organism. There is some difference of opinion as to whether or not the bacteria derive energy from the oxidation of the iron. Some believe that iron is oxidized spontaneously and that the bacteria derive no benefit from it. There is good evidence that some of the iron bacteria obtain the energy for chemosynthesis from the oxidation of ferrous compounds to ferric forms. This is true only of the autotrophic species. The reaction involved may be represented by either one of the following:

(1) $4\,FeCO_3 + 6\,H_2O + \frac{1}{2}O_2 = 4\,Fe(OH)_3 + 4\,CO_2 + \text{Energy}$

(2) $4\,FeCO_3 + 2\,H_2O + O_2 = 4\,Fe(OH)_3 + 8\,CO_2 + \text{Energy}$

The Caulobacteriales or "Stalked Bacteria"

These bacteria are almost entirely aquatic or marine in habitat, although some have been found in the soil. The living cells them-

selves are, in general, much like true bacteria in size and shape, lack visible internal structure, and have the general properties of the class of Schizomycetes with respect to mode of multiplication, nutrition and relation to sunlight.

The peculiarity which sets them apart is the fact that they form a secretion of gum or other matter asymmetrically, so that a stalk is formed as the result of, and consisting of, this secretion. Usually, the stalk is attached to some solid object in the water.

Gallionella Ferruginea

This species, which was formerly included with the Chlamydobacteriales, because it formed a stalk of $Fe(OH)_3$, is now classed with the Caulobacteriales, because it has been found that the organism is neither filamentous nor sheath-forming, but does spin a stalk. Iron is deposited in this stalk. This organism is found in nature as widely distributed as *Leptothrix*, which it much resembles. *Owing to its ability to grow well in the absence of sunlight, it can multiply in water pipes,* whereas *Leptothrix,* requiring sunlight, is held in check to a great extent in such situations. In water conduits made of iron, *Gallionella* causes extensive deposits and incrustations of iron, which may eventually occlude the pipes.

The reactions by which the iron bacteria are presumed to live as autotrophs have been discussed. These reactions are exothermal and are believed to release enough energy to satisfy all of the requirements of the bacteria. The strictly autotrophic iron bacteria, such as *Gallionella ferruginea,* are believed to depend on this reaction, whereas the facultative iron bacteria, including *Crenothrix polyspora* and some species of *Leptothrix*, are not limited to growth at the expense of ferrous iron but can also grow on organic compounds. Thus, those bacteria which are able to grow on either ferrous iron or organic foodstuffs may produce large amounts of precipitated ferric hydrate, when they live on the ferrous iron, and produce accumulations of filamentous fouling material, under conditions where they develop on the organic constituents of the water

The iron bacteria are some of the most important fouling organisms, since they produce not only troublesome accumulations of cell-material, but also still greater quantities of ferric hydrate. It has

been calculated that, as a result of growth of the bacteria on the ferrous iron in solution, there will be about 500 times as much precipitate of ferric hydrate as cells of the iron bacteria. This is of particular importance in establishing the cause of water troubles. It is apparent that, in cases where the iron bacteria have been the sole cause of the trouble, there will be an abundance of ferric hydrate and that the cells of the bacteria will be comparatively inconspicuous. In addition to the iron bacteria there are various other bacteria, including sulfur bacteria and sulfate-reducing bacteria, which are responsible for various transformations of iron. Some bring iron into solution, others cause its precipitation and, in certain instances, the bacteria are responsible for corrosion in one way or another. These reactions may be due to changes in pH, to oxidation or reduction, to production of sulfide, to differences in CO_2 concentration, or to the formation and decomposition of organic compounds of iron, all of which can be brought about by micro-organisms. These reactions affect inorganic compounds of iron in solution or in the solid state, organic compounds, and even metallic iron.

It is important to establish the characteristics of the different bacteria, in order to understand their relationships to the various changes which iron undergoes.

The ways in which these *non-specific bacteria* may cause changes in the iron content of water by altering the environmental conditions are:

a. Cause changes in reaction. Increase in acidity tends to bring iron into solution, while decrease in acidity tends to cause precipitation.
b. Cause changes in degree of oxidation and reduction. Oxidation tends to favor precipitation, whereas reduction favors solution.
c. Produce and decompose organic compounds of iron. Organic iron compounds which are slightly ionized tend to remain in solution, but decomposition of slightly ionized organic compounds of iron leads to iron precipitation.
d. Cause changes in the CO_2 content of water. Increase in CO_2 tends to favor solution, large amounts of CO_2 may cause precipitation, and decrease in CO_2 favors precipitation.

The Sulfur Bacteria

Some of the bacteria increase the acidity and thus tend to dissolve iron; under specific conditions insoluble iron sulfate may be produced.

The Sulfate-Reducing Bacteria

Iron becomes precipitated by a direct reaction with sulfide, which is produced by sulfate reduction. These bacteria also affect the anaerobic corrosion of iron.

The development of iron bacteria may manifest itself in several ways. There may be hard deposits, which tend to fill up the pipes and reduce their water-carrying capacity, as with tuberculation. Slime and accumulations of filamentous bacteria may form on the walls of pipes. These bacteria may cause high turbidity and discoloration of water and be responsible for some of the most unpleasant tastes and odors, which are produced directly or indirectly as the dead bacterial cells are decomposed by other microorganisms. Cases of very profuse development of the filamentous iron bacteria have been referred to as "water calamities", which are more intense phenomena than the ordinary "red-water" plague.

Surface waters may cause difficulties, due to the iron content of the raw water as well as the iron which is taken into solution from pipes and other equipment. Larson (11) reports a case where the water was iron-free upon leaving the plant but where there was as much as 8 ppm of iron at the end of the line a short distance away, giving rise to "red water."

Alexander (12) states that, even though water from deep wells may be free of bacteria and odors when first tapped, bacteria and their products may appear after the deposit has been drawn upon for some time. The result is formation of slime and development of iron and sulfur bacteria in the tanks and pipes, causing the water to have an objectionable odor and taste.

The iron bacteria are typical water organisms, yet *they are not normal inhabitants of water that does not contain an appreciable amount of iron in solution.* They are further characterized by their usual capacity for accumulating ferric hydrate around their cells, which gives them a brown to rust-red color, easily recognized under the microscope.

The iron bacteria are fouling organisms and not agents of corrosion. It sometimes happens that the surface of the fouled metal shows evidences of corrosion, but in such cases it is probable that the corrosion was caused only indirectly by the iron bacteria.

Although it is important to establish the mechanism of precipitation, this information is not always necessary in order to deal with the troublesome accumulation of iron deposits in water-distribution systems. Nevertheless, more definite information is needed regarding the metabolism of these bacteria, which may serve as a guide for the development of more effective control measures. The pertinent fact remains that these *iron bacteria occur in accumulations of precipitated iron and are concerned in the formation of these accumulations.*

Several physiological factors that have been recognized in the past are touched upon briefly, as an aid in the understanding of how to go about creating unsuitable conditions for further development of these bacteria, or destroying them.

Temperature

Some of the iron bacteria show preference for low temperatures. *Gallionella ferruginea* grew under laboratory conditions from 0° C. to 22° C., as reported by Lieske, with an optimum temperature of 6° C. This organism has been commonly encountered in springs, cool waters and in water pipes. A temperature of 40° or 50° C. seems to make their life untenable. Species of *Leptothrix* have also been found in waters at 1° and 2° C., but their optimum is reported to be somewhat higher than *Gallionella,* about 15° C.

Light

The iron bacteria are not sensitive to light and have been found in exposed locations, in the shade, as well as in pipes where light is commonly excluded. However, *Leptothrix* seems to favor the presence of some light, whereas *Gallionella* has been found to be completely independent of sunlight.

Concentration of Iron

The iron bacteria are definitely affected by the presence of dissolved iron, but they tolerate considerable variations in iron concentration. Though they have been found in waters with 10 to 30 ppm

of iron, they also occur where the iron content is as low as 0.1 to 0.3 ppm, *especially* in moving water, where the supply of iron is continuously renewed.

Reaction

The mechanism of reaction of iron bacteria is not definitely established, but there are indications that for many of the organisms slightly acid reactions, such as those caused by solution of considerable amounts of CO_2, are most favorable. With regard to tuberculation, Reddick and Linderman (13) state: "Our investigations to date lead us to believe that an alkaline iron-bearing water, having only a small content of organic matter, will not tuberculate, but that a slightly acid water containing iron and having a high organic matter content will readily tuberculate." Wilson (14) controlled fouling due to *Crenothrix* by making the water alkaline (pH 8.5) with sodium carbonate. Control may have been effected by making the reaction unfavorable to the iron bacteria, or it may have been due to the elimination of iron, manganese or organic matter, upon which the bacteria depended for growth.

Oxygen

The iron bacteria are aerobic and, as such, require the presence of free oxygen. In stagnant waters they are found only at the surface, but they may find conditions favorable for growth below the surface, adjacent to green plants which liberate oxygen through photosynthesis.

Organic Matter

There is much conflicting evidence regarding the influence of organic materials on iron bacteria, but it has been definitely established that some of these organisms can grow on organic media and it appears probable that at least some of the organisms, which are now classified with iron bacteria, actually require organic matter for growth. It is significant to report, however, that no one has succeeded in obtaining growth of *Gallionella* in organic media. This response is similar to that of some other autotrophic bacteria and suggests that *Gallionella* may indeed be strictly autotrophic.

Sources of Nitrogen

The amounts of nitrogen required by the iron bacteria are very small, compared to the requirements for iron, and it is probable that the nitrogen content of most waters meets their needs.

Control of Corrosion-Inducing Bacteria by Chlorination

Little work has been reported on the subject of control of iron bacteria by super-chlorination and break-point chlorination, especially in connection with corrosion correction in pipe systems. Just how much corrosion control can be effected by the destruction of iron bacteria is still problematic, but the little that has appeared in the literature looks very encouraging.

Carroll (15) has written about the destruction of iron bacteria in the water supply of the Federal Homestead Project at Arthurdale, W. Va. The supply encountered has a daily consumption of 14,000 gal. The raw water is obtained from wells and it is unfortunate that he did not include an analysis of the water. However, laboratory analysis determined that the taste and odor conditions were due to the growth of *Crenothrix*. The reservoir had been covered with a ½-inch deposit of "brownish masses of flocs" along the walls and the top of the water was completely covered. The reservoir was drained and scrubbed with a solution of chlorine and $CuSO_4$. After treating the walls and cleaning the reservoir, ammonium sulfate was added in the treatment, to maintain a chloramine residual through the reservoir and, if possible, through the distribution system. With a chlorine residual as high as 2.0 ppm at the pump, it was never possible to reduce tastes and odors, but it was still noticeable in the hot water, and the tastes and odors recurred a couple of times during the summer. In October, 1939, super-chlorination was applied as a new method of treatment.

Instead of "dechlorinating," ammonia was added at the reservoir, to convert the residual chlorine to chloramines. A dose of 9 ppm was found to give 2 ppm (chloramine) in the system. However, the chlorine odor was so strong that the dosage had to be reduced to 4 ppm at the wells. "Now the residual is at 2 ppm after the pump and at the reservoir, after a 75-minute contact period, 1.0 ppm. It should be noted that not liquid chlorine, but HTH, is being used and no

form of ammonia is now being added. After the water flows through the reservoir, which has a theoretical detention capacity of more than 72 hours, the chlorine residual in the distributed water is 0.03 ppm."

"The treatment resulted in satisfactory conditions during the summer of 1940. The growths did not develop on the reservoir walls during that summer and the distribution system problems 'appear' to have been controlled," the author states.

A somewhat more recent comprehensive report in the literature by Arba H. Thomas of the Armco Steel Co. has some revealing experiences. Thomas states (16) that the so-called "iron-consuming" bacteria do not actually devour metallic iron as a food, but do require ferrous iron for their sustenance and growth. As he pictures it, they consume ferrous iron in aqueous solution and excrete it through their cell walls as red ferric hydroxide or other insoluble ferric compounds. In regard to corrosion abatement, he states that there have been many instances where an ordinary mineral analysis of the water and the Langelier index would indicate the water to be *non-corrosive*, and he traces such discrepancies to the presence of iron or sulfur-bacteria. In one instance of this, where no corrosion had been encountered in other localities, sections of the pipe began to perforate at the bottom less than two years after installation. Upon examining these pipe sections, tubercles up to about two inches in diameter were found. These tubercles were opened, giving off an obnoxious "pig-pen" odor. This odor led the investigators to search for some type of dead organism undergoing putrefaction. *Crenothrix* and *Leptothrix* were confirmed by a laboratory investigation. The conclusion reached was that, due to a low-velocity flow, nests of deposits of organisms were formed on the bottom of the pipe, with resulting formation of oxygen-concentration cells conducive to pitting. These findings persuaded the Armco people to investigate further and laboratory tests were initiated. They took samples of scale-free iron and steel sheets, and completely immersed them in flowing water, contained in porcelain, enameled circular containers (see Figure 2). The efficiency of the chlorine treatment was demonstrated in a convincing manner. After chlorine was introduced to the water, it was noted that the heavy growths present began to loosen and fall from the specimen within 12 hours. In three days the entire accumulation had

been removed. This is a vivid and practical demonstration of the efficiency of the chlorine treatment (Figure 3). The one disturbing result in these investigations is that Thomas reports less corrosion as the dissolved-oxygen content was increased from 0.3 to 9.0 ppm, supported by photographs, but contrary to common knowledge.

It was found that if chlorine is introduced so that the residual amount in the water is in the vicinity of 0.5 ppm, most of the less hardy types, such as *Leptothrix, Crenothrix,* and many of the sulfate-reducing forms, can be destroyed. In Middletown, O., the location of these studies, the city water was also treated with chlorine. This eliminated red-water complaints. The treatment was also extended to the air-conditioning water, where previously trouble had been encountered by corrosion within the coils. This treatment was the only way to get rid of accumulated growths and maintain cooling efficiency at normal level.

History of the Maynard Water Supply

On May 25, 1888, the Massachusetts Legislature passed an act enabling the town of Maynard to construct a water-supply system. Water was to be taken from a pond, situated in Stow and Hudson, and flow by gravity through a 12″ vitrified-clay pipe three miles to a receiving well, located on the outskirts of town. From here it was to be pumped into the system, including a 1½-mil-gal reservoir. This was to be circular in form and built of field stone, imbedded in mortar.

A contract was entered into on August 14, 1888, with a contracting firm to construct the water system, with the provision that all work must be completed on or before December 1, 1888. Only a small fraction of the work was completed at this time, however, and the town therefore hired another contractor the following spring. After a short time he asked to be relieved from his obligation and his request was granted.

The Water Commissioners, together with a special investigating committee, decided therefore that it would be to the town's advantage to complete the work themselves. It is interesting to note that the special investigating committee stated at that time that the pumping station, built by one of the previous contractors, would not stand very long, as it was of very poor construction. At the present

FIG. 2.—CORROSION-TESTS SET-UP (ARMCO STEEL CO.)

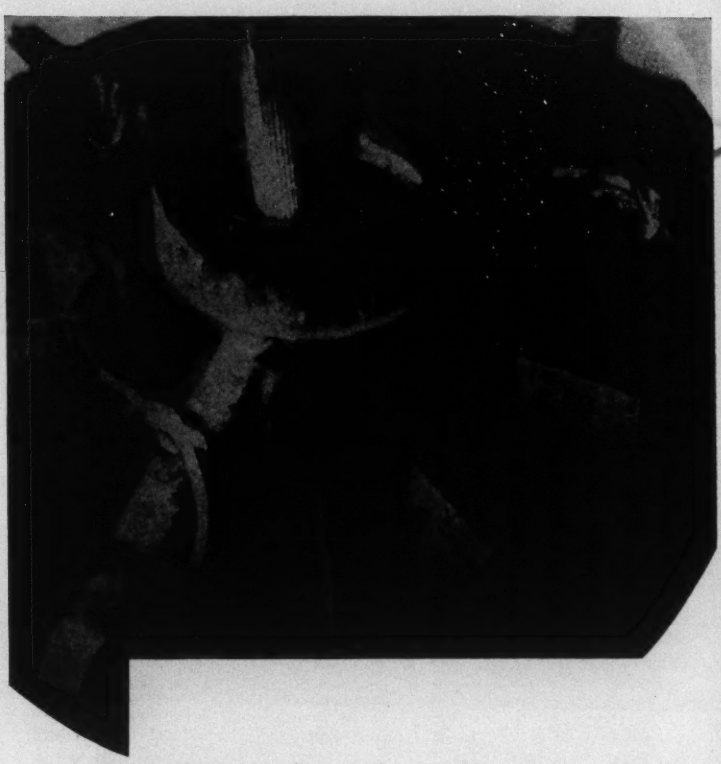

FIG. 3.—CHLORINE EFFICIENCY IN REMOVING BACTERIAL CORROSION (ARMCO STEEL CO.)

time the building is in better condition than some built at a later date.

The machinery installed in the pumping station consisted of one large, compound-condensing, high-and-low-pressure steam pump, capable of delivering 1 mgd, and one high-pressure pump as an auxiliary. Two tubular steel boilers of 85 hp each were to furnish the necessary power.

By 1921 the pumps were so worn that it was felt they should be replaced. A used, Laidlaw-Dunn-Gordon, flywheel pumping engine with a Myer riding cutoff valve, capable of delivering 1 mgd, was installed. This unit remained in operation until 1932, when a Diesel pumping unit and a gasoline-driven stand-by pumping unit were installed.

The gravity feed line from the pond to the receiving wells did not give satisfactory service and, therefore, by 1941 changes were necessary. In that year, a new station was constructed at the pond and a new 10" force main laid from the new station to the old station, whence the water goes into the distribution grid. Two electrically driven DeLaval pumps were installed: one with 350-gpm and the other with 250-gpm capacity. In 1949 the 250-gpm unit was replaced with one capable of delivering 500 gpm, due to increased demands.

Each year additions were made to the distribution system, until now practically the entire town is serviced by this water supply at White Pond. In 1948 there were 1,745 services and the average daily draft or consumption equalled 386,041 gal. In 1949 an additional 35 services were provided, and the average daily consumption rose to 412,803 gal, or 60 gal per capita.

Present Condition of the Maynard Distribution System and Water Quality

The quality of the water supplied to the town of Maynard from the White Pond source has been the cause of much difficulty to the water department for many years. It had become increasingly apparent that something had to be done about "red water" condition and the accompanying taste and odor problems.

Incrustation due to bacterial activity and their end-products has decreased the carrying capacity of the pipes to a bare minimum in many instances. The degree of corrosion which is experienced may be best described by two examples. In one case, when a fire hydrant was turned on full force, the connected fire hose could be manually compressed. This points up clearly the seriousness of the situation. Another illustration of how far corrosion has proceeded was recently demonstrated when a short piece of pipe, which was replaced as part of the regular program, was subjected to a flow test. It was observed

that the pipe had become incrusted to the extent that it was almost completely filled with a semi-solid fibrous mass and brownish deposits, leaving little openings for water to pass through. Upon applying a water pressure of 90 psi on one end of the pipe, only a small trickle was observed at the other end! These two instances are believed to be sufficient to describe the seriousness of the situation at Maynard.

The purposes, when pilot-plant studies were first contemplated in the fall of 1947 were:

(1) To provide a cleaner and more palatable water to the consumer.
(2) To stop the corrosive action in the pipes.
(3) To insure adequate water pressure at all times in every point of the system as designed for, and to give necessary fire-fighting protection.

In order to accomplish these goals and to learn more about the details of this complicated problem, a pilot plant was constructed in the water-pumping station at White Pond (see Figure 4), with a flow of about 2.3 cu ft per min, or 25,000 gpd.

Description of the Pilot Plant and Some of the Results Obtained

Upon a preliminary analysis of the causes of water-quality depreciation in the distribution system, the conclusions arrived at were that this was due to electrochemical reactions, such as accompany any corrosive water in contact with metals, and to the chemical and physical reactions of the products of living organisms that have been accumulating within the system. It was recognized that any organic matter, either present or continuously entering the system, would provide food for these living organisms.

Therefore, the first step would be to reduce the organic matter entering the system; secondly, to reduce or destroy completely the living organisms in the water and in the distribution system. Up to this time, for several years, the raw water had been receiving a constant chlorine dosage from a hypochlorinator on the suction side of the pumps. This had been resulting in a combined or chloramine residual, after the pumps, of 0.35 ppm. It may very well be that this

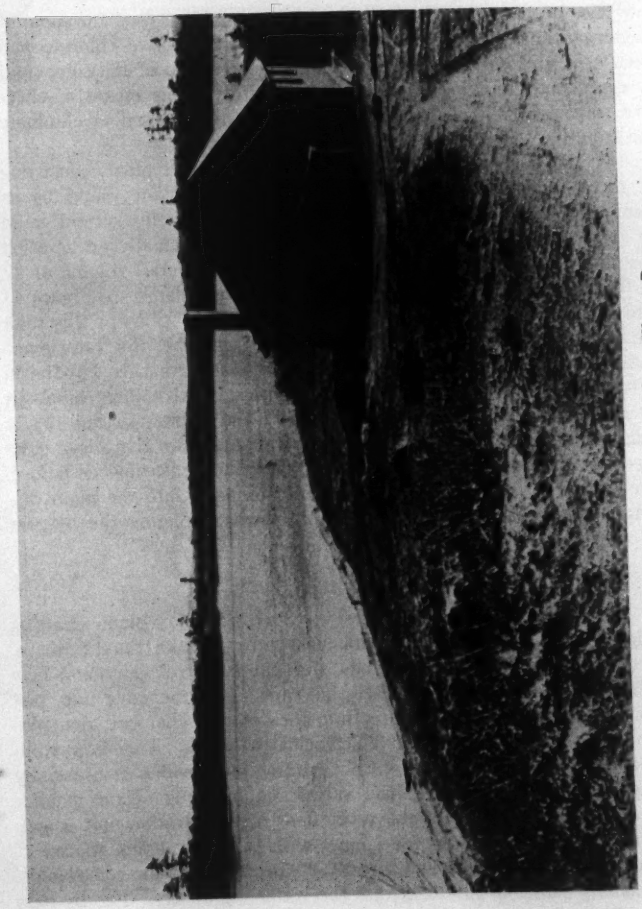

FIG. 4.—THE NEW PUMPING STATION AT WHITE POND. LOCATION OF PRESENT PILOT PLANT STUDIES.

low dose of chloramine actually had been providing food for some of the organisms present in the system, after the active chlorine had been used and only the nitrogen portion or residual of the compound or compounds remained in the water. Thirdly, some means of effective corrosion control and pH adjustment was proposed to eliminate the troubles.

It was decided to build a pilot-scale treatment plant, consisting of three tanks, arranged in series, so that the plant would be as compact as possible and the flow of water through this system could be continuous. The first of these three tanks is actually an aeration chamber. Its dimensions are 3′ x 3′ x 3′, or an overall volume of 27 cu ft. From this tank the water overflows a weir plate (see Figure 5) into a second tank or mixing chamber. The dimensions of this tank are identical with the first. From the mixing chamber the water overflows another weir-plate into a contact and settling basin. This basin is 9 ft long, 3 ft wide, and 3 ft tall, with a total volume of about 80 cu ft. The basin contains 5 round-the-end baffles, spaced 1½ ft apart. Six inches from the end of this contact basin there is a side-overflow weir-box, with a weir-plate of the same dimensions as before, discharging into a 2″ pipe. This pipe leads back into the main discharge pipe from the pumping station, thus completing the by-pass through the pilot plant.

Aeration Unit

As shown on the isometric view of the pilot-plant drawing (Figure 5), the raw water enters from a by-pass on the 12″ main, on the pressure side of the pumps, through a control valve and flow meter into the bottom of the aeration tank. Into the same line, just after the meter and before entry into the aeration chamber, the solution feed from a new W. & T. chlorinator enters. This is a volumetric chlorinator, manual-control, solution-feed, which is especially adapted to meet accurately the varied requirements of the smaller water works. Four inches above the floor of the aeration unit, a galvanized pipe in the form of a square, with ⅛″ diam. holes, spaced 2″ on centers, is suspended and directly connected to an air compressor, furnishing sufficient air to agitate the water vigorously. The by-pass from the main is controlled to carry 2 cfm, or 14.96 gpm. In addition

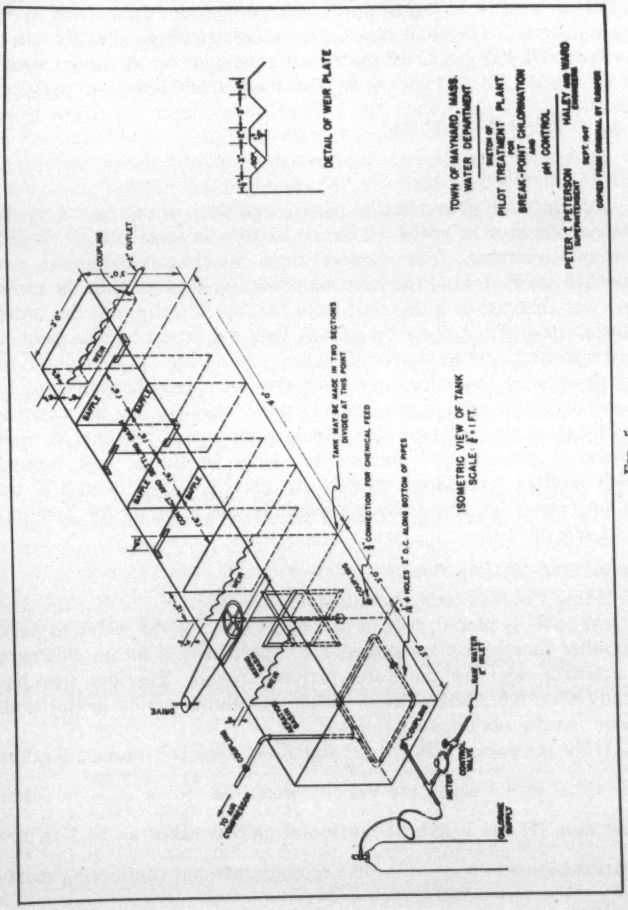
DETAIL OF WEIR PLATE
TOWN OF MAYNARD, MASS.
WATER DEPARTMENT
SKETCH OF
PILOT TREATMENT PLANT
FOR
BREAK-POINT CHLORINATION
AND
pH CONTROL
PETER T. PETERSON
SUPERINTENDENT
HALEY AND WARD
ENGINEERS
SEPT. 1947
COPIED FROM ORIGINAL BY R.GRUNE
ISOMETRIC VIEW OF TANK
SCALE: 1/4" = 1 FT.
TANK MAY BE MADE IN TWO SECTIONS DIVIDED AT THIS POINT
CONNECTION FOR CHEMICAL FEED
HOLES 2" O.C. ALONG BOTTOM OF PIPES
COUPLING
OUTLET
WEIR
BAFFLE
DRIVE
TO AIR COMPRESSOR
RAW WATER INLET
METER
CONTROL VALVE
CHLORINE SUPPLY

FIG. 5.

to this, a quantity of 2 gpm enters from the solution feed of the chlorinator injector. The total flow is, therefore, 16.96 gpm or 2.27 cu ft per min (24,500 gpd). If the effective volume for detention equals 3′ x 3′ x 2′ 6″, or 22.5 cu ft, the theoretical detention period is $\frac{22.5}{2.27} = 9.9$ or 10 minutes.

Mixing Chamber

A four-bladed, vertically placed agitator, driven by a ¼ hp electric motor at a speed of about 10 rpm is installed, to provide mechanical mixing. The chemical feed, which was originally connected to the bottom of the tank (as shown on Figure 5), in the meantime was changed to a dry feed from the top, directly into the water. Solution feed with a chemical such as lime was found to be a cumbersome operation and no degree of accuracy in dosing could be obtained. The dry feed, as practiced now from the top, should be supported by a solution pot as soon as possible, *i.e.* rather than feeding the chemical directly upon the water surface, which is not a good practice. A small amount of concentrated solution or slurry should be first formed, which is then introduced directly by gravity. The theoretical detention period for this tank is essentially the same as for aeration, about ten minutes.

Contact and Settling Basin

Along the longitudinal dimension, after the first 12 in., the first vertical baffle is placed, with 6 in. on the side for the water to pass. The other four baffles are spaced 1′ 6″ apart, with 6 inches clearance at alternate sides for the water to pass around. The end weir has already been described. The detention or contact period in this tank can be readily obtained as follows:

If the maximum area for the water to "squeeze" through is taken as 3′ x 1.5′ or 4.5 sq ft, the velocity would be $\frac{Q}{A} = \frac{2.27}{4.5} = 0.505$ ft per min. If the length of horizontal path is taken as 20.5 ft, the detention period $= \frac{20.5}{0.505} = 40.5$ minutes, without considering short-circuiting.

In this analysis we assumed that dead-space losses will make up for the actually higher velocity, due to small areas of flow-through section, where the water is temporarily speeded up. However, we can state that the total detention period for the pilot-plant set-up is very nearly one hour. Practical experience has indicated that actual detention period is somewhat less than an hour—closer to 50 or 55 minutes, actually—which may be due to short-circuiting in the tanks. In order to get reliable design figures for any final treatment plant, the present set-up lends itself excellently to conducting flow studies, to establishing the exact characteristics of these basins and to adjusting their sizes to conform to the actual or theoretical contact periods that will be established as required to perform the various tasks for each unit.

The whole structure, as it now exists, is made from galvanized steel sheet-metal, which lends itself excellently for this work. The reasons for the arrangement and the purposes of each unit in the proposed treatment process will be briefly discussed. As far as possible, merits or demerits, which have so far been established, are pointed out.

It may be mentioned here again for clarity that, before these studies were undertaken, the water from White Pond received no form of treatment, other than chlorination to a 0.35-ppm combined residual at the pumping station. The raw-water intake of the pumping station is approximately 15 ft below the surface of the lake. The chemical analysis of the water is shown in Table 2.

TABLE 2.—CHEMICAL ANALYSES OF THE MAYNARD WATER SUPPLY

A. Analyses Made by the Massachusetts Department of Public Health

Year	Turbidity	Color	Ammonia Free	Ammonia Album.	Nitrogen NO_3	Nitrogen NO_2	Chlorides	Hardness	Alk.	pH	Fe	No. of samples
1940*	—	2	.014	.071	.07	—	2.2	8	6	6.2	.05	5
1946	3	8	.003	.100	.05	—	3.0	12	10	6.7	.08	4
1947	2	3	.012	.060	.02	—	2.8	10	7	6.8	.05	4
1948	1	3	.004	.068	.02	—	3.0	11	7	6.4	.03	1†

*It was also found in the 1940 report that the residue on evaporation was 22 ppm.
†This singular sample was recorded as the only one in March, 1948.

B. Analyses Made by the Author March 1-20, 1948

Type of Determination	Number of Determinations Performed	
Total Alkalinity = 7.0 ppm as $CaCO_3$ (P alkalinity = 0)	(6)	
Hardness = 8.0 ppm as $CaCO_3$	(3)	Average figure
CO_2 Content = 10.0 ppm as CO_2	(12)	Varied from as low as 5 ppm to as high as 14 ppm**
pH = 6.10	(5)	Measured with electro-potential meter
Ca^{++} = 6 ppm as Ca^{++}	(2)	p. 60, Std. Methods, 9th Ed.
Dissolved Solids = 40 ppm	(3)	
Dissolved Oxygen = 11.2 ppm at 2° C.	(4)	Winkler Method wth Azide Modification
Per cent D.O. Saturation = 81.0%		
Average temperature during the total period = 3° to 5° C.		

**It should be stated that the raw-water pH, as measured at the plant by a color comparator (which was checked to be correct within 0.2 pH units against the electro-potential pH meter), has changed from substantially pH of 6.1 to 5.4 during the times these tests were performed, with the lower value obtained on March 20th. This must be ascribed to the spring turnover in the pond (see Figure 4), upsetting the alkalinity-acidity equilibrium, as must be expected.

Results

Upon examination of these analyses certain facts stand out immediately:

(1) That this water is extremely soft.

(2) That the CO_2 content is high, as might be expected.

(3) That the amount of organic material is relatively low (also reflected in the low color and turbidity readings).

(4) That the pH of this water is low and that this situation, combined with the low alkalinity, explains, at least to a great extent, the corrosiveness of this water in the distribution system. It also indicates immediately that, in order for a thin film of $CaCO_3$ to be deposited, a relatively large amount of chemical, such as lime, must be added.

(5) That the break-point for this particular water can be reached with a relatively low dose of chlorine applied (see Figure 6). This is reflected in the low organic-matter content and nitrogen compounds dissolved. Therefore, a rather low, free and stable residual can be carried throughout the system, once the organic and bacterial growths in the pipes have been destroyed, including the iron bacteria.

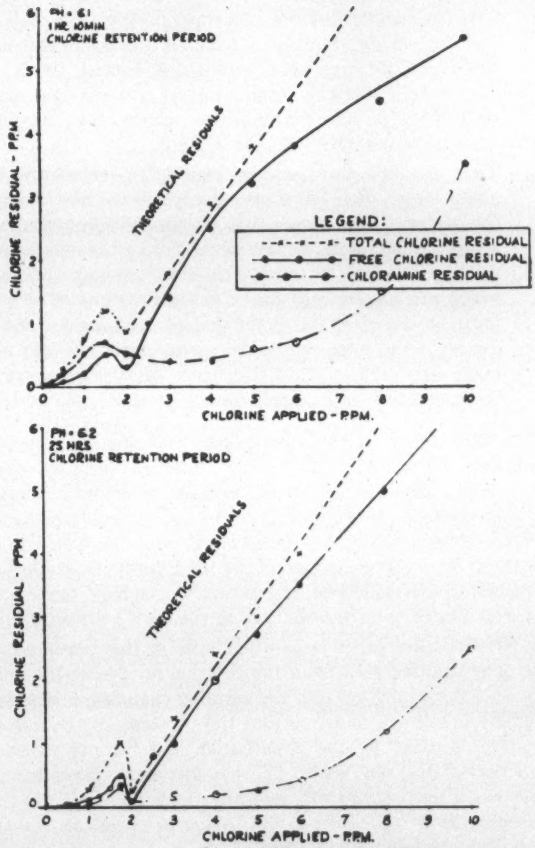

FIG. 6.—BREAK-POINT CHLORINATION GRAPHS OF WHITE POND RAW WATER.

(6) The iron content of the raw water is low. The U.S.P.H.S. Drinking-Water Standards have set the maximum limit of the combined iron and manganese content at 0.3 ppm. Above this, these minerals impart color ("red water"), stain fixtures, and "chalybeate" waters—*i.e.*, they impart a peculiar flat and iron-like taste.

(7) That the dissolved-oxygen content is relatively high—about 80%. This helps also to explain the corrosiveness of the water. This shows that the dissolved-oxygen content should by no means be increased, but rather decreased. The same holds true in regard to the iron bacteria, most of which are aerobic and thrive in the presence of oxygen. It must be stated at this point that at the time the dissolved-oxygen tests were made the spring turnover had already made itself felt, so that this figure of 80% may not be as representative as it should be.

It has been found at this pilot plant, with aeration provided as described, that the pH value of the raw water has been increased by 0.1 to 0.2 units. This method of pH increase would be costly indeed and not help corrosion in any way, due to the corresponding increase in dissolved oxygen, but it has been found that the CO_2 content is reduced about 30%. The amount of air used, however, could not yet be established and it would be interesting to compare the economics of removal of this 30% of free CO_2 as to chemical neutralization.

The *main* reason for this aeration unit in this plant is a little different. The solution feed from the chlorinator, dosing theoretically 2 ppm or 16.7 lb per mil gal into the aeration chamber, lowers the pH just about by 0.1 to 0.2 units, so that the increase in pH, due to the CO_2 removal, is offset by the chlorination and the pH value is returned to that of the raw water. This is fortunate, inasmuch as the raw water has a low enough pH, and any further lowering in the pH that can be avoided represents a real saving in chemicals for $CaCO_3$ saturation and pH adjustment, later.

Another important purpose of this tank is the removal of objectionable odors, due to the active oxidation or destruction of bacterial and organic life. It was found that the 0.35-ppm residual,

previously maintained with the hypo-chlorinator, produced a bad taste-and-odor problem during the summer months in the town of Maynard. Housewives complained about not being able to boil tea and coffee any more without the inclusion of an obnoxious medicinal taste and odor. It was proven that, by carrying a free residual, this trouble can be overcome. The water leaving the pilot plant has no taste whatsoever and a definite improvement over the raw water can be noticed. It should also be remembered that it is not always the amount of organic material and bacterial life present that produces offensive odors and tastes, as much as the types of organisms present. Undoubtedly, saprophytic bacteria are present in the pond, liberating CH_4, H_2S, CO_2 and other substances whose tastes and odors are greatly pronounced and aggravated when attacked and broken down by chlorine. In order to get rid of these objectionable and foul odors, this aeration—with a 10-minute contact period—has proven its worth up to now. The 10-min contact period was found to be just a little short for break-point formation within the aeration tank, but the main odor- and taste-producing substances seem to be removed. The actual break-point is not reached until the mixing unit. It seems, advisable, therefore, that, in the final design and construction of a treatment plant, the aeration unit be given a somewhat greater detention period.

Another feature which might be feasible to incorporate in a final design would be some form of forced-air ventilation over the aeration unit, continuously displacing the volatile substances absorbed by the atmosphere. It would, of course, be even better if some form of selective atmosphere inducement could be attained over the aeration tank. However, the economics generally do not permit such refinements. Another disadvantage of the present aeration unit is that the amount of air cannot be measured. It is estimated that about ½ cu ft per min per sq ft of tank area is added. It seems that either the amount or the pressure, or both, are too great, for the agitation imparted to the water is very vigorous. The oxygen content is increased from 80% to 88% or 90% upon leaving the aeration unit. An attempt must be made to minimize this rise in dissolved oxygen. Naturally, the CO_2 removal is directly affected by the rate of aeration and a happy medium must be struck, depending on the actual CO_2

content, which varies with the seasons, within limits, possibly more than oxygen.

In passing, it should be mentioned that another purpose of basic importance was to provide good contact between the chlorine and all the water treated, in order to attain maximum efficiency of chlorination.

From the aeration unit the water flows, with a combined total residual of 1.5 ppm of chlorine, into the mixing chamber (see Figure 7). Here the chemical or chemicals are added to the water to the point of $CaCO_3$ saturation and for pH adjustment.

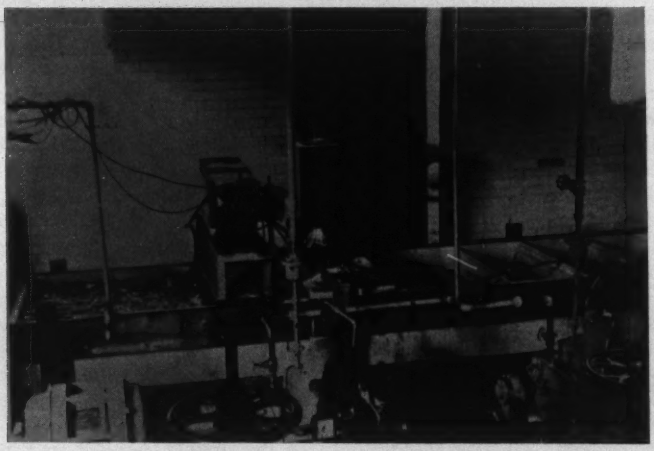

FIG. 7.—VIEW OF PILOT TREATMENT PLANT.
Showing (a) Aeration Tank, (b) Mixing unit with dry feeder mounted over it, (c) Contact and Sedimentation Chamber. (Pumps are shown in the foreground.)

This water needs an increase in both the (Ca^{++}) and the $(CO_3^{=})$ concentrations, to reach or surpass the solubility product concentration, required to lay down a protective film of $CaCO_3$ and prevent further metal from going into solution in the system.

The use of hydrated lime, $Ca(OH)_2$, has this double effect of

furnishing Ca^{++} ions to the water and the hydroxyl ions which combine with the bicarbonates to form $CO_3^{=}$. The latter may be represented as follows:

$$HCO_3^{-} + OH^{-} = CO_3^{=} + HOH$$

The effectiveness in raising the pH by $Ca(OH)_2$ is very high; and were it not for the disadvantages of lime, in adding to the hardness of the water (1 ppm of lime as $Ca(OH)_2$ adds 0.54 ppm of carbonate hardness as $CaCO_3$), as well as the fact that overdosages above the $CaCO_3$-saturation point produce undesirable caustic alkalinity, the use of this chemical might represent the universal answer. The difficulties of solution feed and sludge problem have largely been overcome by the application of dry-feeding apparatus.

From the marble test and the application of the Langelier formulation, as derived by E. W. Moore (17), in the most useful and practical form, it was indicated that a lime dosage of 10 ppm as $Ca(OH)_2$, with a corresponding pH = 9.32, is required for $CaCO_3$ saturation of this water. The values found by the marble test and the application of Moore's equation vary very slightly. These differences may very easily be due to the variation in pH of the raw water on different days of sampling and testing, or to the change in pH in the marble test due to prolonged standing. (Compare Figures 8, 9, 10 and 11).)

The correct lime dosage of 10 ppm means, therefore, a theoretical increase in the hardness (carbonate) of 5.4 ppm or a 67.5% increase in hardness, based on 8 ppm as the initial hardness in the water. A total hardness of 13 ppm still represents a very soft water but the people of Maynard and industrial establishments may object, being used to such extremely soft water.

The use of soda ash was, therefore, initiated with three immediate advantages:

(1) In solution feed, which had to be practiced until recently when a dry feeder was obtained, the distinct advantage of the soda ash in going more quickly into solution and being completely dissolved was demonstrated.

(2) The problem of having some lime settle out and make accurate dosing of the chemical impossible was eliminated when soda ash was used.

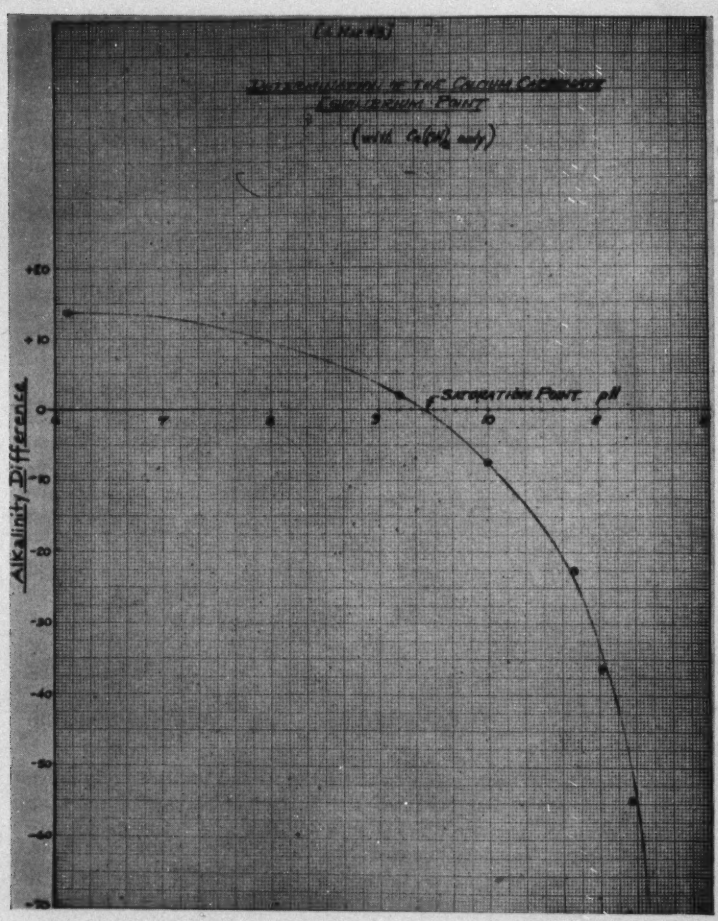

FIG. 8.—MARBLE TEST TO DETERMINE $CaCO_3$ EQUILIBRIUM POINT BY USE OF LIME.

(3) Soda ash does not increase the carbonate hardness and a dose of 50 ppm of Na_2CO_3 resulted in a pH of only 8.6 on plant scale.

This does indicate the lower efficiency of pH adjustment by the use of Na_2CO_3. The cost of treatment with soda ash alone, wherever possible, is about 10 times that when lime alone is used. (Soda ash is about 2 times as expensive as lime and the dosage of soda ash required is about 4-5 times the amount.) Actually, this is painting a darker picture for soda ash than is needed, for there would be some savings in the hardness, as compared to lime.

A treatment with 100% lime proved that a dosage of 10 ppm of lime as $Ca(OH)_2$ would saturate the water with $CaCO_3$ at a pH of 9.32 (see Figure 9).

A treatment with 20% lime and 80% soda ash proved that a dosage of 3.57 ppm of lime as $Ca(OH)_2$ and 14.25 ppm of Na_2CO_3 as $CaCO_3$ would saturate the water with $CaCO_3$ at a pH of 9.35 (see Figure 10).

A treatment with 50% lime and 50% soda ash showed that a dosage of 7.2 ppm of lime as $Ca(OH)_2$ and 7.2 ppm of Na_2CO_3 as $CaCO_3$ would be required to give the desired $CaCO_3$ saturation at a pH of 9.30 (see Figure 11).

It can thus be shown that, for the case of the water at Maynard, a saving in the hardness-increase may be effected by the use of, say, a 20%-80% lime-to-soda-ash combination. To predict a definite lime-ash proportion dosage for this water would be a mistake, the variations in the chemical constituents of the raw water being sufficiently great to upset such a definitely stated optimum dosage. It is therefore suggested that two dry feeders be maintained over the mixing tank, one for each chemical, with a continuous-recording pH meter, which will give the operator ample opportunity for adjustments in his chemical dosing. The change in the market prices and general availability of chemicals, when considered under present-day conditions, will also show that the recommended set-up provides for a more flexible operation.

For the first few months at the start of the treatment, from experience of similar treatment operations reported elsewhere, it would be best to operate this plant on the supersaturated side of $CaCO_3$—

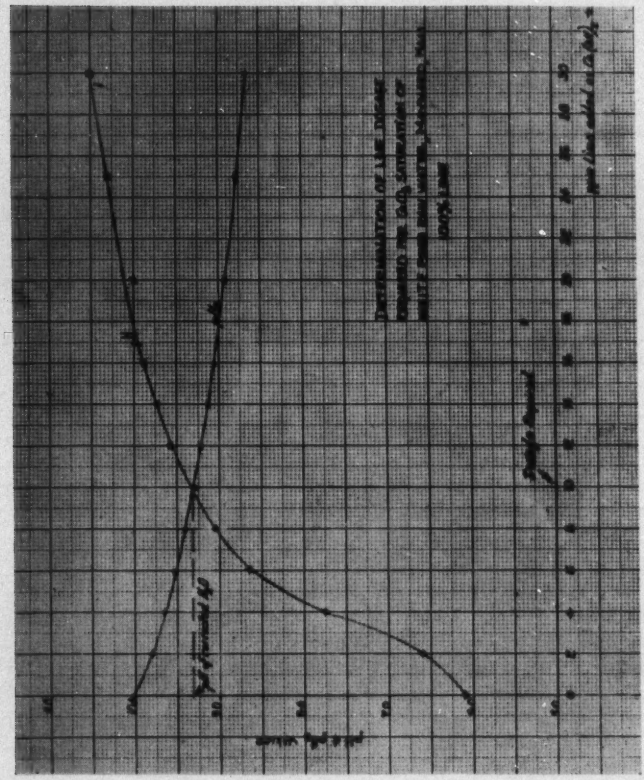

FIG. 9.

i.e., about 15 ppm of lime as $Ca(OH)_2$ (or its equivalent)—and at a corresponding pH of about 9.8, to insure the formation of a good protective layer of $CaCO_3$.

During this series of tests, the chlorine residual was measured and it was found that the free-chlorine residual has no effect on the

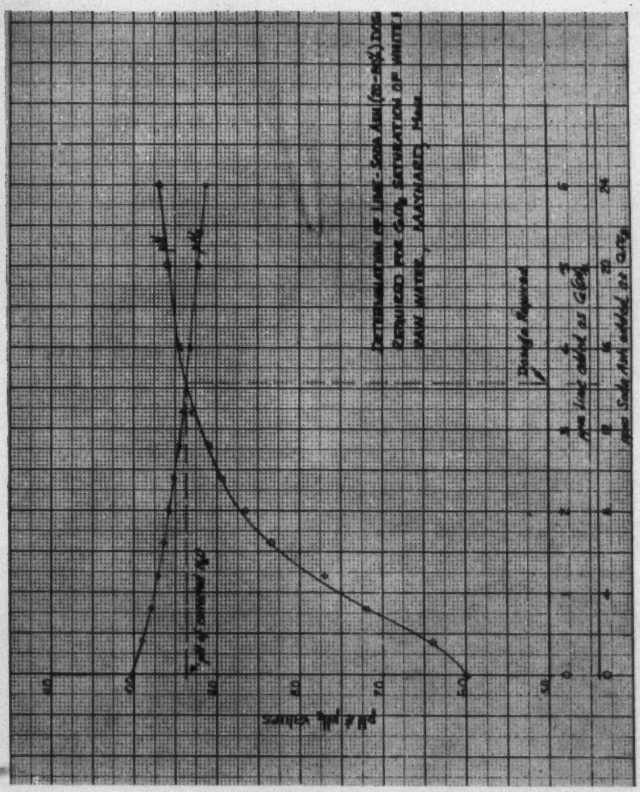

FIG. 10.—DETERMINATION OF LIME-SODA ASH (20-80%) DOSAGE REQUIRED FOR $CaCO_3$ SATURATION OF WHITE POND RAW WATER, MAYNARD, MASS.

chemical treatment, as would be expected from a consideration of the terms in the Langelier expression. (The effect on salinity, if at all measurable, would be too small to warrant any correction of the value of pH_s and this has practically been borne out in test runs.)

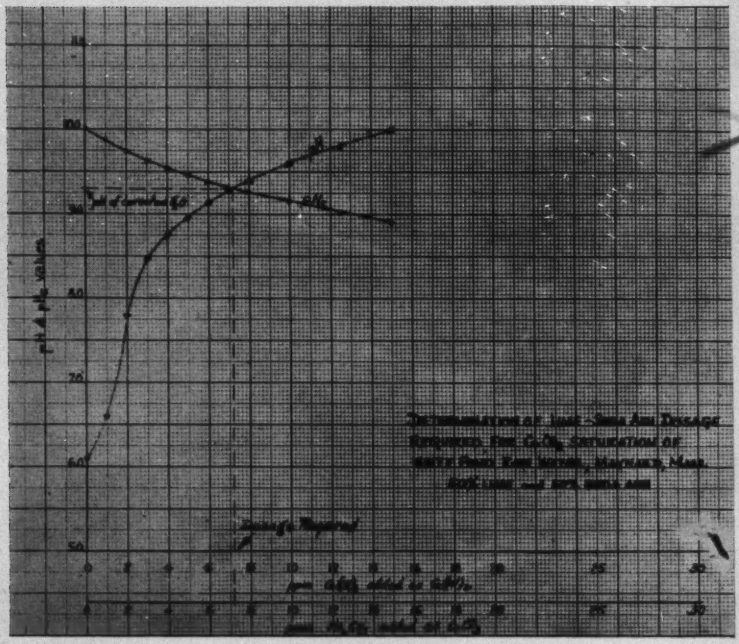

FIG. 11.

The third and last feature of this treatment is the contact and settling basin. This basin provides ample opportunity for the reactions, which may only be initiated in the mixing chamber, to go to completion, and for stabilization of the water under these new conditions, before entry into the system, to take place. It was noticed that, when the dosages into the mixing tank were adjusted during trial runs, over-dosage of chemicals would at times result in the settling out of a precipitate. Especially, if a high dose of lime and soda ash should temporarily find its way into the mixing chamber, co-precipitation would result according to:

$$Ca(OH)_2 + Na_2CO_3 = CaCO_3 + 2\,NaOH.$$

The basin is therefore an added safeguard, providing sufficient contact time to carry down any substance present that may precipitate and deposit at, or near, the entrance of the distribution system, with consequent clogging and reduction of the carrying capacity. The basin will aid the operator in being able to deliver water of more uniform quality to the system, especially with variations in composition such as occur every spring and fall.

A disadvantage of the design of the present contact and sedimentation chamber is that the basin is too long and thus provides additional opportunity for O_2 to dissolve. The dissolved-oxygen content of the water at the end of the contact basin was almost 100% with March temperatures and this should be reduced, if possible, without sacrificing settling-out time for chemicals. There is also room for improvement on the present baffle design.

Some kind of sludge-removal provision must be made in the prototype. In the pilot-plant design an outlet for the sludge was hardly called for, in the final design, however, some arrangement must be made to remove adequately the sludge which may form on the bottom of this tank and thus reduce the capacity and contact time considerably with operation.

The fact that the chlorine residual throughout this basin is 2 ppm shows definitely that a stable residual has been reached. There are no tastes or odors in this water, except what might be termed slightly chlorinous.

Discussion of the Langelier Index

The test for determining whether a given water is saturated with respect to calcium carbonate has for many years been the "marble" test, in which the water is placed in contact with calcium carbonate and its increase or decrease in alkalinity noted. In order to determine the pH at the carbonate saturation point of an undersaturated water, a curve is drawn with pH as abscissas and change of alkalinity, resulting from the addition of $CaCO_3$, as ordinates (see Figure 8). At each value of pH the alkalinity is obtained before and after the $CaCO_3$ addition. The point of intersection of the curve representing

alkalinity and the abscissa is the pH of the carbonate saturation point. This method is tedious and has really become obsolete.

More recently Langelier (18) has shown how the calcium-carbonate equilibrium may be calculated directly from the composition of the water, without resorting to the marble test. Moore (17) has shown how the Langelier equation can be used in place of the marble test, to compute directly the quantities of chemicals necessary to produce saturation in any given water. There are at least three reasons for preferring this method. One is that the laboratory work is cut down to a minimum; secondly, that the marble test is somewhat unreliable unless the analyst is very skilled; thirdly, the time involved to attain true equilibrium after $CaCO_3$ saturation may sometimes be a matter of days rather than hours. It has been the author's experience that leaving the saturated samples in a cold room for 3 and 4 days was necessary to produce the desired equilibrium. Another disadvantage is that by the use of McLoughlin's method one gets a definite pH at the saturation point, which can be translated into plant operation only if lime alone is used. If, however, treatment with two chemicals, such as lime and soda ash in combination, is proposed, the point of saturation will not immediately indicate the exact proportions or dosages required.

Therefore, more accurate determinations of the carbonate saturation point were made by the use of the simplified Langelier equation, as proposed by Moore. This method gives the relationship between the pH, alkalinity and calcium content of any water which is saturated with $CaCO_3$—*i.e.*, $pH_s = (pK_2 - pK_s) + pCa + pAlk$.

In his original paper, Langelier (18) stated that the composition of water is only indirectly a factor in corrosion. Any water, regardless of its composition, after a certain period of contact with a clean iron surface will cause corrosion of the metal. If, however, certain of the products of the corrosive action are held at the boundary surface, the corrosion rate is reduced and, if the conditions are favorable, further corrosion will be practically eliminated. The problem resolves itself, therefore, into one of forming a suitable protective coating.

In natural, oxygen-containing water, $CaCO_3$ is the salt which is most useful in forming or, together with rust, assisting in the forma-

tion of a self-healing or natural protective coating. A rust coating not containing $CaCO_3$ is too porous and is not sufficiently dense and continuous to offer protection, and may even accelerate corrosion in the form of pitting.

In order that $CaCO_3$ may deposit on the pipe interior, it is necessary that the product of the concentration of the calcium and carbonate ions present in the water *at a given point in the system* shall exceed the solubility product constant of $CaCO_3$ at 25° C.—$K_{sp} = 1.6 \times 10^{-8}$. If water is deficient in *either* of these ions, so that K_{sp} is not equalled, not only will the carbonate film not form, but also any existing film will be dissolved.

It is important to note that, as the film is deposited in the pipe, the separate calcium- and carbonate-ion concentrations in the water may decrease to the point where the solubility product is no longer exceeded, in which case the water is incapable of furnishing further protection. Applied to a given distribution system, this would mean that the pipe nearest the source would receive the greatest protection. This tendency, however, is offset by the fact that the deposition from a supersaturated solution is not instantaneous, but requires, for a low degree of supersaturation and at lower temperatures, several hours or even days. Also there is reason to believe that under conditions of operation there is a leveling process, whereby material deposited at one point may be picked up by solution and deposited at a point farther out in the system. This could be brought about by irregularities in the treatment and by temperature changes.

The algebraic difference between the actual pH of a sample of water observed and its computed pH_s is the logarithm of its degree of carbonate saturation. This has been called the "Langelier or $CaCO_3$ Saturation Index." Actually, this index is the logarithm of the ratio of the hydrogen-ion concentration, which the sample must have if it were saturated (*without change in composition*), to its actual hydrogen-ion concentration. If the index is zero, the sample is in equilibrium. A plus sign before the numerical value of the index indicates over-saturation and a tendency to lay down a protective coating of $CaCO_3$ in the pipes. A minus quantity indicates under-saturation or a tendency to dissolve an existing carbonate coating. Expressed mathematically:

$$\text{Saturation Index} = \text{pH}_{\text{(actually observed)}} - \text{pH}_{\text{(saturation)}}$$

$$= \log \frac{(H_s^+)}{(H^+)}$$

In Langelier's expression for pH_s, the effects of variable salinity upon saturation are provided for in the term $(pK_2 - pK_s)$. It was Moore who evaluated these constants and placed the use of the equation on a more practical level. In his paper (17), he has simplified Langelier's equation to the form:

$$pH_s = K - \log \text{ of ppm Ca (as Ca)} - \log \text{ of ppm Alk. (as } CaCO_3),$$

and he has given a table for the values of the constant "*K*" for various concentrations of dissolved solids and temperatures. It should be remembered that this form of the equation applies strictly only for the range of $pH_s = 6.5$ to 9.5. For values outside this range, the complete and original equation must be used. In the case of the water analyzed at Maynard the pH_s of the raw water was found to have a value of 10.0.

Significance of the Saturation Index

From the foregoing discussion it might be assumed that a zero saturation index in practice would be ideal, at a given temperature. This is correct, provided that the index is zero at those points in the system where the water is most active. Since many corrosion troubles occur in hot-water systems, it would seem that an index of, say, —0.5 at 20° C. (which is equivalent to 0.0 at 80° C.) might prove out best for most supplies.

It should be emphasized that the saturation index is an indicator of directional tendency and of driving force, rather than a measure of capacity. The capacity of a water to lay down protective coatings depends directly upon the property of the water to resist change in the value of its index.

Moreover, the saturation index does not indicate the quantity of chemical required to establish equilibrium. In general, the lower the value of pH_s, the greater will be the dosage required.

Summary and Conclusions

In conclusion:

(1) It was found that the forces that are at work in causing corrosion are many and that corrosion cannot be stopped by the isolation and removal of any single reaction or element.

(2) Many methods of corrosion have been suggested or applied, and various degrees of success have been obtained. There is no universal treatment so far. However, for the soft New England waters, the cheapest and most effective treatment in the long run is the limestone contact-bed, lime or lime-soda-ash treatment.

(3) The chemicals which have been used in the treatment of a water to reach the carbonate saturation point are: hydrated lime ($Ca(OH)_2$), unslaked lime (CaO), soda ash (Na_2CO_3), caustic soda ($NaOH$) and limestone ($CaCO_3$), the latter in the form of contact beds.

(4) It has been noted that the addition of lime has the double effect of increasing both the calcium and the alkalinity, with consequent lowering of pH_s. Lime is, therefore, generally considered the most satisfactory and suitable alkali for the correction of soft New England waters. There is one disadvantage with lime, inasmuch as hydroxide alkalinity may result in some soft waters which contain very small amounts of CO_2 and bicarbonate alkalinity. Hydroxide alkalinity does not aid in saturating the water with respect to $CaCO_3$, unless there is present a sufficient amount of CO_2 and bicarbonate alkalinity to convert the added lime to calcium carbonate:

(1) $$Ca(OH)_2 + Ca(HCO_3)_2 + H_2O + CO_2 = 2\,CaCO_3 + H_2CO_3$$

(2) $$Ca(OH)_2 + H_2CO_3 = CaCO_3 + 2\,H_2O$$

It can be seen and calculated stoichiometrically from these reactions that the dosage in ppm of pure hydrated lime should not exceed the *sum* of 1.68 x ppm CO_2 and 0.74 x ppm bicarbonate alkalinity as $CaCO_3$ in the water.

Any lime added in excess of these quantities exerts only the single effect of its calcium content. These facts explain why some soft waters, which are low in CO_2 and alkalinity besides, cannot be successfully corrected for their corrosiveness by the use of lime alone. A suitable *combination* of lime and soda ash, with respect to $CaCO_3$

saturation, can therefore be derived. Besides, the disadvantage of lime in adding hardness to the water is overcome by the use of soda ash.

(5) It was found that a dose of at least 10 ppm of lime as $Ca(OH)_2$ is required for carbonate saturation of the water at Maynard. If the alkalinity and the CO_2 content, in the mixing tank, are found to be 6 ppm and 3 ppm respectively, a lime-soda-ash treatment is found to be necessary. The sum of 1.68×3.0 plus 0.74×6.0 is equal to 9.48 ppm. This indicates that, at any time when the dosage of lime might be stepped up to above 10 ppm (equal to a positive saturation index), the real possibility of adding hydroxide alkalinity exists. This fact, combined with the savings in hardness-increase by the use of soda ash, has led to the advocacy of the proposed dry feed of 20% lime and 80% soda ash, or similar proportions, as was practiced at the time of the conclusion of the original work.

(6) Iron bacteria have been found in iron-bearing and corrosive waters in contact with iron surfaces. *Gallionella* and *Crenothrix* have been observed under the microscope, which had grown on a sample of steel wool in a jar test of untreated water at Maynard (see Figure 12). This is not pointed out here to produce conclusive evidence of any sort, but it is common knowledge that these iron bacteria exist, feed, grow and deposit when dead in the pipe lines. On the basis of scattered evidence of the influence of organic matter on the iron bacteria, it may be tentatively stated that *Crenothrix* and *Leptothrix* are facultative autotrophs and that *Gallionella* is strictly autotrophic. In waters containing relatively large amounts of organic matter, it is common to encounter *Crenothrix* and *Leptothrix*, whereas in water low in organic matter *Gallionella* is prominent. The latter can grow well in the absence of sunlight, as compared to *Leptothrix*, of which the opposite has been found.

(7) The exact mechanism of how the iron bacteria contribute to corrosion is still undetermined. One school of thought has it that these non-pathogens create concentration-cells and cause tuberculation and pitting. Another school believes that the active oxidation, furnishing the energy for the iron bacteria in part, helps to speed up the cycle of iron going into solution. Whatever the truth, which may very well include both arguments and depend also on pH, the effec-

FIG. 12.—JAR TESTS FOR CORROSION EXPERIMENTS.
From left to right: (a) Water treated with Calgon; (b) Water treated with chlorine and lime—notice minor rust formation; (c) and (d) Untreated water or typical "red water".

tive removal of these organisms and their foods may solve a great portion of the problem.

(8) Break-point chlorination, still in its infancy, carries a free and stable residual of high destructive power, as far as organic life is concerned, once the break-point dosage has been passed.

Whatever the mechanism, oxidation or poisoning of the cell or a combination of effects, we know that destruction of bacteria can be very effectively carried out by chlorine residuals produced, once the "break-point" has been passed.

As reported by Fair, Morris and Chang (19), at a pH above 10 there is very little, if any, of the free residual in the form of HOCl, but all is in the form of the rather inactive OCl^-. The bactericidal power of OCl^- is approximately only 1% of that possessed by hypochlorous acid.

At the Maynard pilot-plant aeration unit, where the pH is sub-

stantially 6.0, practically all (98% at 0° C.) the chlorine residual is in the form of HOCl. The break-point is not quite reached in the 10-minute contact period given to the water in the pilot plant. For this reason the unit should have a somewhat longer detention period, say 15 minutes, since at present the "break" is produced in the mixing unit. Under these conditions the free HOCl will very effectively destroy any bacteria or organic life present in the raw water.

With the introduction of the chemicals for corrosion prevention, the pH is raised to 9.0-9.5 and at this pH, with the present status of the distribution system, it would take a long time, if at all, to destroy and carry out all the iron bacteria and bacterial slimes, now occluding the inside of the pipes.

For this reason it is necessary to resort temporarily to a more drastic treatment. Upon completion of a treatment plant, with everything in readiness to lay down a protective layer of $CaCO_3$, all growths, tuberculations of iron bacteria, slimes, etc., must be attacked and destroyed by a high chlorine dosage. The system must then be hydrant-flushed. This plan has been adopted and carried out successfully elsewhere. In those instances, the operation was carried out at night; certain parts of the system were isolated consecutively and the hydrants opened to drain the dirty waters and sloughable deposits. This process may have to be repeated for some time, because, as bacteria break loose, new layers may become exposed to attack by chlorine, thus requiring additional flushings. This depends entirely upon the actual condition of the distribution system. The loss in water and other financial considerations compare favorably with present costs of laying new pipe.

Immediately after this operation is successfully concluded, treatment to calcium-carbonate saturation must be started, preferably with a saturation index of + 0.3 or 0.5, at least, for an initial period.

After treatment has been practiced at this pH, say 9.6 or 9.8, for the interim period, the dosage can be slowly and gradually reduced. By continuous dissolved-oxygen, pH, and alkalinity tests at stations along the system, a continuous check can be maintained. As long as the pH does not fall very short of the pH_s, say 0.5 approximately, no $CaCO_3$ layer that has been formed will be redissolved. It is actually anticipated that the corrosion prevention can be effec-

tively carried out at a pH of no higher than 9.0. At this pH the effectiveness of a free-chlorine residual is impaired in the system—about 5% only of the chlorine in the form of HOCl at 0° C.—but the crucial disinfection has already been effectively carried out in the aeration chamber.

It was found in these pilot-plant studies that the free residual obtained at the end of the settling and contact chamber is 2.00 ppm at a time when the lime- soda-ash treatment was being carried to a pH as high as 10.5 in the mixing tank, proving no effect.

Acknowledgment

This paper was inspired as a report in partial fulfillment for one of the graduate courses in Sanitary Engineering at Harvard University. Grateful acknowledgment for pointing out this interesting and timely problem must go to Mr. Stewart H. Newland. In preparing the original report, expert guidance and sustained interest were generously provided by Professors E. W. Moore and J. Carrell Morris. Messrs. Haley and Ward provided the author with the necessary field equipment to carry out those laboratory determinations made at the pilot plant. Mr. P. Peterson, Superintendent of the Maynard Water Works, was of immense help and assistance in the successful execution of this work.

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THE CORROSION OF DOMESTIC GALVANIZED HOT-WATER STORAGE TANKS

BY I. LAIRD NEWELL*

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STEEL tanks for the storage of both hot and cold water are subject to rapid corrosion, unless either the water is treated or the steel surface is given a protective coating. Protective coatings can be divided into two classes, organic and inorganic. The organic coatings are made up of materials such as paints, rubber and synthetic resins, whereas the inorganic coatings are generally composed of glass, enamel or Portland cement. Cathodic protection, such as by externally applied potentials or galvanic coatings, has been used successfully for tank protection when the water is cold, but only the inorganic coatings and cathodic protection have found much favor for hot-water tanks. This paper will be limited to a discussion of galvanized-steel tanks for the storage of hot water.

There appear to be at least three significant factors controlling the corrosion of galvanized-steel, hot-water storage tanks. They are temperature of the water, presence or absence of copper, and types of negative ions present in the water. Various investigators have noted the effect of these factors and some of the more important investigations are cited here.

It was noted as early as 1742 that zinc coatings were protective to iron (1), and that this protection was due to the galvanic cell, formed when steel surfaces were exposed. Since steel surfaces having continuous zinc coatings are perfectly protected, the life of this surface is of some interest. It depends on the thickness of the coating, the chemical composition of the water, and factors such as temperature, pH and oxygen concentration. According to Anderson (2), high-grade rolled zinc has been found to corrode nine times as fast in aerated distilled water at room temperature as in aerated hard water under similar test conditions.

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Hydrogen-ion concentration has a wide effect on the corrosion rate of zinc (3). The penetration in inches per year may vary from as much as 0.20 at pH 3.0 to 0.001 at pH 7.0, to < 0.0004 at pH 12.0 and back to 0.20 at pH 14.0.

Galvanized-steel tanks for the storage of hot water in domestic water supplies have been in use for more than 50 years. The excellent results obtained, in many instances, not only with galvanized tanks but with galvanized piping have made the use of galvanized steel quite common. Some installations, made as long as 30 or 40 years ago, are frequently found to be in good condition today. However, with the more prevalent use of copper and brass pipe, connected to galvanized, hot-water storage tanks, and with the tendency to keep the stored water at higher temperatures, it has been found that with some water supplies galvanized tanks will have extremely short life.

During the past 20 years, it has become apparent that zinc, under certain conditions, will fail to give adequate protection to steel. Of the three factors previously mentioned, the temperature and composition of the water appear to control the electrochemical behavior of the zinc-iron system and, under certain conditions, cause failure of the zinc as a protective agent.

Schikorr (4) appears to be the first investigator to show that, under certain conditions, zinc could become cathodic to steel and thus actually accelerate the corrosion of the steel, rather than protect it. As a result of his investigation, he found that, if the temperature of the water in galvanized pipes is 120°F. or below and if no large amount of air is present, then the zinc does not become ennobled sufficiently to produce a couple with any exposed iron, to cause the iron to act as a soluble electrode. However, with water temperatures as high as 160°F., the zinc becomes more noble than the iron and relatively rapid corrosion of the iron pipe takes place.

G. L. Cox (5) found that, when zinc specimens were immersed in aerated distilled water for some days at various temperatures, a maximum in corrosion rate was found at about 140°F. Cox believed this to be due to the amount of oxygen available at various temperatures and also to the difference in corrosion product, formed at various temperatures.

Maconachie (6) confirmed the work of Cox, showing that a

maximum corrosion of zinc occurred at a temperature of around 140°F.

Kenworthy and Smith (7) found in their work that zinc would not protect steel, where the steel was exposed to certain solutions, when heated to 185°F. They believed that, in order to have satisfactory life for galvanized steel, the carbon dioxide should be less than 5 ppm and there should be a total hardness of more than 100 ppm.

Bonilla (8) found that galvanized pipes carrying hot water showed pitting which was more severe than obtained with ungalvanized iron pipes. He also found that the zinc coating on these pipes remained after 15 years and believed this to show that the zinc coating was cathodic to the steel.

Gilbert (9) studied the effect of water composition and temperature on the electrochemical behavior and corrosion of zinc-iron couples. He found that zinc can become cathodic with respect to steel in both distilled and hard water. A temperature of 140°F. is necessary, but when the zinc has become cathodic, the temperature may be lowered to some extent without reversal. Since the chief reaction occurring in neutral solutions in the corrosion of zinc is oxygen absorption, the presence of dissolved oxygen is necessary for zinc to become cathodic. Where the zinc coating is one produced by hot galvanizing, a zinc-iron alloy layer is formed, which becomes cathodic to steel in aerated water, whether hot or cold, and is more cathodic than zinc under similar conditions. Thus, corrosion of the galvanized layer may stop when the zinc-iron alloy is reached. However, pitting can occur and usually penetrates into the steel.

Hoxeng and Prutton (10) also investigated the effect of chemical composition of the water and water temperature. They confirmed the work of Gilbert that zinc may become cathodic to steel under certain conditions. They found that chloride and sulfate ions decreased the probability of reversal of the zinc-steel couple, while bicarbonates and nitrates promoted such reversal. Increasing temperature increases the probability of reversal, but depends on electrolyte composition.

Figure 1 shows graphically the effect of the bicarbonate ion on the potential of zinc, when measured against a saturated calomel

FIG. 1.—EFFECT OF BICARBONATE CONCENTRATION ON ZINC POTENTIAL. Time, 6 hr; Temperature, 140° F.; Solution—SO_4 10 ppm, NO_3 5 ppm. (Na salts added to distilled water)

From data by Hoxeng and Pratton

electrode. The fact that steel has a potential of —0.6 to —0.7 volts against a calomel electrode indicates the zinc to be cathodic to steel under these conditions.

The results obtained by these investigators show that, in order for galvanized steel to have satisfactory life in hot-water storage tanks, the temperature of the water should be maintained below 140°F. It would also be desirable to have a minimum concentration of bicarbonate and nitrate ions and a substantial quantity of sulfate and chloride ions.

Another factor influencing the life of galvanized-steel water-storage tanks is the presence of traces of copper in the water entering the system. The increased use of copper and copper alloys for piping, fittings and valves of domestic water systems has had a marked effect on the life of galvanized tanks.

McKee (11) has found that a concentration of 1 ppm of copper sulfate in a cooling system caused the removal of the galvanizing from pipes in as short a time as two months.

Kenworthy (12), who studied the problem of copper and galvanized iron in the same water system, concluded that the rate of corrosion of galvanized iron or zinc is materially increased by the presence of traces of copper in water. As little as 0.1 ppm of copper causes a definite increase in corrosion rate. With amounts of copper up to about 0.3 ppm, the degree of corrosion is proportional to the amount of copper, but with copper concentration of 10 ppm, the corrosion rate is less than proportional. The copper appears to deposit as small metallic particles on the surface of the zinc. Galvanic cells then form, with the copper particles as cathodes and the zinc surface as the anode. With many natural waters, sufficient copper is dissolved, by the simple passage of water through copper pipes, to affect the rate of corrosion of galvanizing, but not sufficient to have a noticeable loss from the copper pipe. The amount of copper dissolved by a water will depend on the composition of both pipe and water. Increased carbon dioxide will increase the copper dissolved and it is suggested that the free carbon dioxide be limited to 2 ppm.

The author has made a study of 7 galvanized, domestic water-storage tanks, which have been in service for periods ranging from 431 to 667 days. Six of these tanks were equipped with single

magnesium rods to give additional cathodic protection. The magnesium rods were not centered on the axis of the tank, but were offset as much as several inches. The magnesium rod in the seventh tank became disconnnected from the tank after a few days and it is believed that the rod had no effect on the corrosion of the tank. These tanks were operating in a soft water at temperatures from 165°F. to 170°F., the water having the analysis shown in Table 1.

TABLE 1.—WATER ANALYSIS

pH	6.6	
Conductivity (mhos)	60	
Alkalinity	6	ppm
Total Hardness	17	"
Fixed Solids	30	"
Chlorides	2.8	"
Free Carbon Dioxide	3	"

The tanks were connected to piping systems having copper or copper alloys in some part of the influent piping. All of these tanks showed severe pitting-type corrosion, as shown in Figures 2 and 3. It was also noted that the tubercle density was higher on those areas of the tanks farthest from the magnesium rod. This indicates some protection by the use of the magnesium anode.

Pit depths were measured with an inside micrometer, after cleaning off the tubercle with a revolving bristle brush. It was noted that most of the tubercles and pits were characterized by the presence of a hard disc over the center of the pit. The pits showed depths ranging from 0.009 to 0.075 inch. This disc was shown to contain significant amounts of copper. Figures 4 and 5 show photographs of typical corrosion pits found in these tanks, while Figure 6 shows a sketch of a tubercle having a copper-containing disc.

Microscopic examination of a section through the corroding galvanized layer showed interlamellar corrosion of the zinc-iron alloy. Figure 7 represents a photomicrograph of the galvanized layer and shows corrosion extending through the zinc layer.

As a result of these tests, the predicted life of these tanks was less than five years, with the probability that any individual tank would not have a life exceeding seven years before failure by

FIG. 2.
Tank Capacity, 52 gal; Service, 432 days; Pit Depth, 0.023 inch max.
Magnesium Rod Connected.

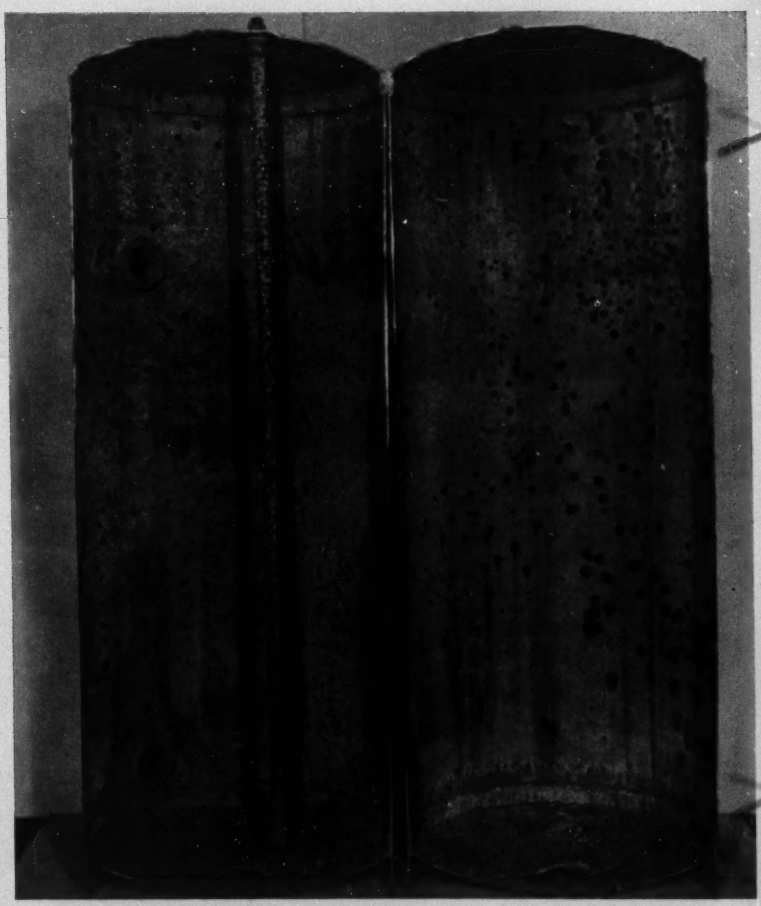

FIG. 3.
Tank Capacity, 52 gal; Service, 450 days; Pit Depth, 0.026 inch max.
Magnesium Rod Connected.

FIG. 4.—TWIN PITS UNDER A SINGLE TUBERCLE, THE PITS HAVING DIAMETERS OF APPROXIMATELY ¼ INCH.

leakage would occur. It is quite likely that difficulties due to "red water" would occur somewhat earlier than the failures by leakage.

Our study has shown that severe corrosion may be experienced in galvanized, domestic, hot-water storage tanks, using a soft water.

Increased corrosion and lower tank life are believed due to:

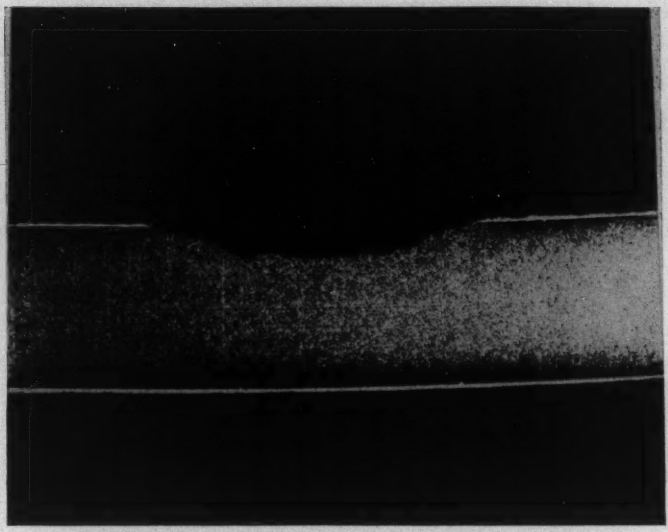

FIG. 5.—PHOTOMICROGRAPH OF SECTION THROUGH A TYPICAL PIT, FROM WHICH THE CORROSION PRODUCT HAS BEEN REMOVED.
This section shows the total thickness of the steel shell and the galvanizing, both interior and exterior.
Magnification, 10X; Etch, 1% Nital.

(1) the presence of traces of copper in the water supplied to the tanks;
(2) operating temperatures in excess of 140°F., which tend to cause potential reversal in the zinc-iron galvanic couple;
(3) the presence of significant amounts of bicarbonates and/or nitrates in the influent water.

Lower corrosion, with consequent longer tank life, may be expected when:

(1) Systems are all galvanized, with no copper.
(2) Pipe is of a resistant copper alloy, such as aluminum brass.

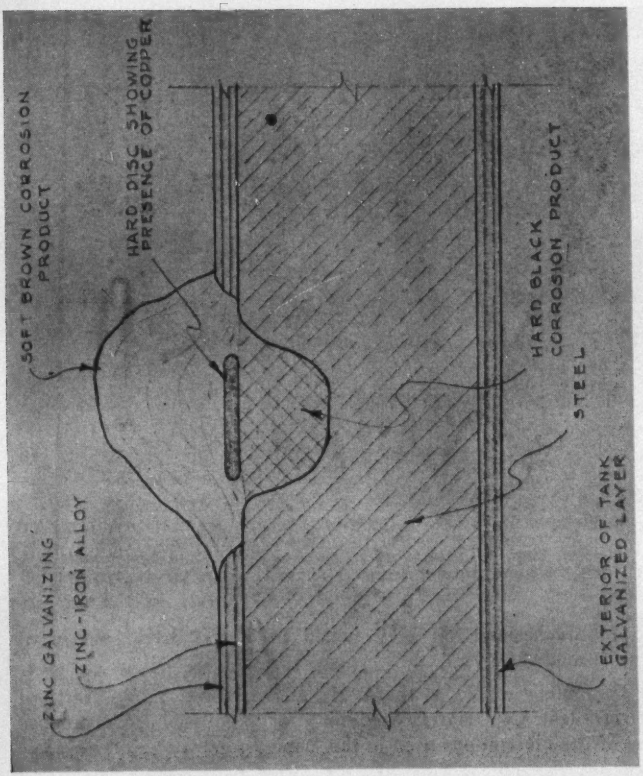

FIG. 6.—SKETCH OF SECTION THROUGH TUBERCLE, SHOWING LOCATION OF COPPER-CONTAINING DISC.

(3) Water is aerated, to remove carbon dioxide.
(4) Water is treated with lime, to react with carbon dioxide.
(5) Copper is removed from water by passing through zinc.
(6) Operating temperature is lowered, to prevent potential reversal.

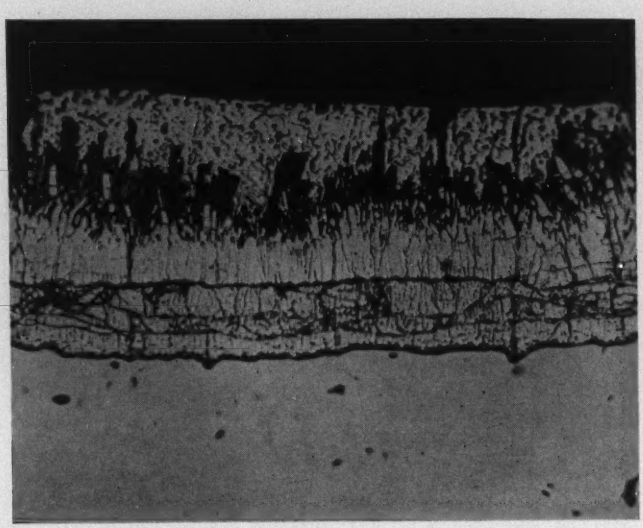

FIG. 7.—PHOTOMICROGRAPH OF SECTION THROUGH GALVANIZED SURFACE NEAR A CORROSION PIT, SHOWING INTERLAMELLAR CORROSION OF THE ZINC-IRON ALLOY. This photo also shows voids leading to the surface of the zinc layer. Magnification, 500X; Etch, 1% Nital.

(7) Magnesium rod is provided in waters having sufficient conductivity.

The author wishes to thank Mr. A. L. Bisbee of the Hartford Electric Light Co., Hartford, Conn., for permission to reproduce many of the illustrations used in this paper.

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Discussion

KENNETH F. KNOWLTON*.—Mr. Newell's paper has been of great interest to me, particularly in two respects. The first is the fact that we must know more about the life expectancy of hot-water storage tanks, built of various materials of widely divergent costs. The second reason is that during the past two years four specific instances of unsatisfactory or questionable performance of galvanized hot-water tanks have been brought to my direct attention as a water-supply chemist.

Length of expected service and quality of performance, weighed against cost, usually govern the choice of material for hot-water storage tanks. Examination of Table 1 shows that the best tanks of galvanized iron enjoy a tremendous price advantage over copper, the most common competitor. Of course, the percentage advantage is less when a complete, automatic heating unit is considered, but there are still a great many users of plain storage tanks.

TABLE 1.—RETAIL PRICES OF HOT-WATER STORAGE UNITS, MAY, 1950

	Retail price
1. 30-gal capacity hot-water tanks only:	
a. Light weight galvanized	$21.00
b. Medium weight galvanized	24.00
c. Double extra heavy (300-lb test) galv.	28.00
d. Copper, 250-lb test	82.35
e. Copper, 350-lb test	105.00
2. Automatic water-heating units, 30-gal capacity, gas-fired:	
a. With galvanized-iron tank	$110.00
b. With monel or copper tank	175.00

The history of the four individual cases of severe trouble with galvanized hot-water tanks will be given individually, since Mr.

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Newell's description of the action of copper seems in large measure to explain at least three of the cases.

Case No. 1.

This was a 40-gal tank, approximately six months old, connected to a heat exchanger on a household steam-heating boiler. The circulating pipe was partly of brass and partly of copper.

At roughly two-week intervals, the circulating pipe near the hot side of the exchanger would become so filled with sludge that it required flushing to restore circulation. Analysis of the wet sludge is shown in Table 2. Active corrosion was obviously present in the system and the dissolved corrosion products were apparently being precipitated by the heat. Upon further investigation, the owner stated that he had used the copper drop pipe from his old copper tank to convey the cold incoming water through his new galvanized tank.

It was recommended that he remove this copper tube and make the cold-water connection at a plug near the bottom of the tank and, if he wished to gain advantage of the remaining depth at the bottom, to use a short piece of tinned pipe inside the tank at this point.

This change was made and six weeks later the owner called to say that his trouble had been eliminated.

TABLE 2.—ANALYSIS OF WET SLUDGE FROM CIRCULATING PIPE TO HOT-WATER TANK IN CASE NO. 1

	Ppm
Iron (Fe)	1,560
Copper (Cu)	22.4
Zinc (Zn)	320
Phosphate (PO_4), unfiltered	24.1
" " filtered	0.80
pH	7.2

Case No. 2.

This tank was an integral part of one of the better makes of automatic, oil-fired hot-water units, having a galvanized tank with a central flue.

At the time I was called in, the unit was approximately two years old and had started giving trouble, because of rusty water,

almost immediately after its installation. In this case, the water temperature had been high—about 160° to 180°. Analysis of the material flushed from the bottom is given in Table 3 and shows high iron and zinc content. So far as is known, the tank had not been previously flushed out.

The jobber who installed the unit flushed the tank thoroughly at this time and installed a magnesium anode, in an effort to control the corrosion.

Two months later the tank was still giving trouble and it was suggested that the cold-water drop pipe inside the tank might be of copper. The jobber was shown a laboratory experiment, with a brass-iron couple in one beaker and iron only in another beaker, which definitely showed the difference in corrosion rates when the two beakers were heated. Immediately the jobber checked the tank and found the suspicion to be fact. The case this time was closed by the jobber's installing a new tank, rather than inconvenience his customer any further.

Of about a dozen identical, or supposedly identical, units sold by this dealer this was the only one to give trouble. Recently the writer obtained this discarded tank and had it split open. The tank is covered with large pits, especially on the central tube, which was hottest, while the area between the pits is still coated with zinc in sufficient thickness to take off chips with a chisel and then to verify the zinc in the laboratory.

TABLE 3.—ANALYSIS OF SLUDGE IN BOTTOM OF WATER TANK IN CASE NO. 2

	Ppm
Iron (Fe)	20,400
Zinc (Zn)	8,750
Magnesium	absent
Phosphate (PO_4)	nil
Insoluble material	904
pH	6.8

Case No. 3.

This is a unit of the same make as No. 2, but gas-fired and installed by a different jobber in a new house, otherwise completely plumbed with copper. Red water caused several calls to the Water

Department to have the street main flushed and in each instance the street main was found to be clean.

Finally the owner was told that the tank probably had a copper tube inside that was causing the trouble.

In this case our contact was with the owner, and he has had no success in getting an adjustment or study from the department store which sold and installed the unit. The only comment from the store was that the water was at fault. At the time of preparing this discussion the unit was still giving trouble and no steps had been taken to correct it.

Case No. 4.

This case covers a group of gas-fired galvanized hot-water heaters in a new veterans' housing project. All piping, including service lines, was of copper tube. We were called at a time when these units were between two and four months old, the complaint arising from a report of turbid, not red or colored, water to the housing authority. Their man had drawn one pint of water from the bottom of a tank and, upon straining it through a clean handkerchief, obtained a cake about ⅛ inch thick of material that looked like gray clay.

Only one occupant in the development had noticed the turbidity at the tap, but all the tanks contained a similar material. Analysis showed the material to consist primarily of zinc hydroxide, zinc phosphate and zinc carbonate.

From this experience we concluded that the zinc normally was removed very rapidly from the inside of the tanks and that, due to its light color, it was not noticed in the hot water until the iron began to corrode and the entire flocculent mass became red in color. Further samples from other miscellaneous tanks seemed to bear this out. Tanks with large amounts of "rusty" sediment, which had not been flushed, were found to have more zinc than iron in the sediment, and those which had been flushed out thoroughly developed only a relatively small volume of sediment, which was mostly iron.

Mr. Newell's observations on the accumulation of copper on the zinc surfaces are very interesting. We have not tried to make any similar tests, but on a few occasions have checked the copper content of water from various taps.

In particular, we have a sampling tap at the filtration plant, which is on a ½-inch copper tube about 50 ft long. Recent samples from this tap showed the first quart to contain 0.8 ppm of copper and, after thorough flushing of several minutes' duration, the water still had a copper content of 0.2 ppm.

In contrast to the reported instances above of troublesome units, I might state that one of our operators has an oil-fired, galvanized hot-water unit six years old, which has given no trouble. In this case the service pipe and all piping to the unit are of galvanized iron. In all of these cases the water supply is the same. Its approximate analysis is as follows:

Carbon dioxide	3 ppm
pH	6.9
Total alkalinity	16 ppm
Sulphate	25 "
Hardness (soap)	45 "
Calgon	1.0 "

It is my opinion that more studies in the nature of those made by Mr. Newell would be well worth while and that the results of the studies should be made generally available to the manufacturers of these products, and particularly to the plumbing industry.

I wish to express my thanks to the personnel of the Water Laboratory of the Massachusetts Department of Public Health for making the quantitative analyses of sludges used in these studies.

THE COST OF OPERATING CONSTRUCTION EQUIPMENT

BY SHERMAN L. ROGERS*

[*Read September 19, 1950.*]

UNTIL the last war the Water Bureau of the Metropolitan District depended almost entirely on rented construction equipment, aside from compressors and trucks, to do its construction and maintenance work. This system consists of about 700 miles of water mains, 44,000 services and about 4,450 hydrants. In both 1948 and 1949 we laid about 18 miles of main and installed about 2,100 services with our own forces, and in 1950 we have already done in eight months about as much as during all of 1949.

Hiring heavy equipment seemed reasonable, until the rental bills began to assume such large proportions that in one year we paid out nearly $15,000.00 to rent a ¾-cu yd backhoe and operator. At this time it appeared that it would pay us to buy one or more shovels, but it was difficult to determine just what the operative costs would be and how far we should go in making these purchases.

Therefore, we have tried to keep fairly accurate cost records, as various items have been purchased, to show whether or not there was any particular advantage in ownership, and this paper reflects the result of this experience.

Having rented nearly all kinds of backhoes in all kinds of condition, we decided to buy first a ½-cu yd backhoe and crane on rubber. This machine, made by the General Excavator Co., has a four-wheel drive and plenty of road clearance, and can move over the road at about 18 mph. While it is possible for this machine to become mired in deep mud, we have taken it through some very bad going.

Soon after this machine was put to work on main pipe-line construction, we began to think of some mechanical aid for service-pipe excavation. Late in 1947, we thought we had the answer and bought a 1/3-cu yd Quickway backhoe, mounted on a Ford six-ton truck.

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This rig is highly portable and takes up only a little more room in the street than an ordinary truck. In easy digging it is "tops" for this sort of work, but we have so much hard digging in our district that we now believe that a slightly larger machine would be not only more efficient but cheaper to operate. This and other makes are made in the ⅜-cu yd size and, when we replace this machine it will probably be with a heavier one.

To complete our line of excavators, we next bought a ¾-cu yd Unit backhoe on crawlers. Although this machine is a full heavy-duty ¾-yard machine, weighing about 20 tons, we had it equipped with a ½-cu yd digging bucket. This gave us a heavy, powerful machine, capable of producing plenty of trench in even the hardest digging, and yet one which dug a trench only 31 in. wide, instead of 39 in. wide, which is about the usual width for a ¾-yd bucket. This materially cuts down the costs of roadway replacements and gasoline consumption is only about 15 gal per day, against about 30 gal per day with the larger bucket.

We also have a 10-ton, Link-Belt yard crane, to handle pipe in our yard, where it was formerly handled by an overhead trolley system on an extensive wooden trestle. The cost of operating the crane is much less than the cost of maintaining the trestle, and there is no comparison in the speed with which it loads and unloads pipe.

We also have two Hough payloaders, used to backfill trenches, a smaller loader on a Case tractor, to load sand or gravel from the yard stockpile, and a cold-patch mixer. There is little or no saving connected with owning a cold-patch mixer, since it costs us practically as much per ton to make cold patch as it does to buy it, except that our trucks can take as little or as much as they need at one time and we can continue to make it during the winter months, when all of the commercial plants are closed down. This feature alone is worth a great deal to us.

Table 1 shows the total yearly cost of operating these machines. These figures represent all money spent for gasoline, oil, tires, and repairs, but overhead expenses and insurance are not included. The Quickway and the General were given complete overhauls last winter, and the cost of this work was added to the annual costs, to get the

average annual costs to date. It is generally recommended that machines of this type be depreciated by the straight method over a five-year period, and the various authorities agree that if machines like these are used 2,000 hours per year, their useful life is likely to be about five years. Since municipal outfits like ours seldom, if ever, operate 2,000 hours per year, a six-year depreciation period has been adopted. Depreciation is a very important item, since it is readily seen that on some machines depreciation is a larger figure than the actual costs of operation and maintenance. From the way in which we use it the Link-Belt crane will undoubtedly have a life of 10 or 12 years but, if the Quickway backhoe lasts out its allotted six years, we shall consider ourselves extremely fortunate.

Table 2 shows the cost per hour of operation. Most of these machines are equipped with hour meters, which are electric clocks, operating only when the ignition switch is on. By using this little device, a surprisingly accurate account of the time that the machine actually runs can be obtained and the figures given are the average use per year under our conditions. The hourly time shown is not necessarily the actual time that the machine was on the job, but is the actual hours of operation with the motor running, and this should be kept in mind when comparing our costs with the cost of rented machinery, since you usually pay for a rented machine as long as it is on the job, and regardless of whether the motor is running or not. The difference between the figures in the last two columns represents the renter's insurance, overhead costs and profit, and is also a portion of our savings due to ownership. Other savings are due to always having the machines available at short notice, to help excavate for leaks during the night or on week-ends. It is evident from these figures that it is probably better not to buy, unless a piece of equipment can be used several hundred hours per year, because depreciation goes on anyhow and idle equipment is a distinct liability.

Most of our compressors are truck-mounted, with truck bodies especially built for carrying small tools, equipment and men. Some units have a regular, 105-cu ft, gasoline-engine-driven air compressor, and others have 105-cu ft air compressors driven through a power take-off by the Ford truck engine. There are other, older units, where a 105-cu ft gasoline-engine-driven compressor is mounted on a smaller

TABLE 1.—COST PER YEAR (LESS OPERATOR)

Unit	1946	1947	1948	1949	Overhaul cost	Average cost: Bare	Average cost: With depreciation
Link-Belt Crane—10-ton	$169.91*	$431.99	$216.31	$218.06	—	$288.79	$1,030.04
General—½-yard	—	698.86‡	1,220.26	1,189.33	$1,089.33	1,476.91	4,511.00
Unit—¾-yard	—	—	1,422.63	1,460.78	—	1,441.70	3,983.03
Quickway—1/3 yd., incl. Truck	—	—	1,741.06	1,871.21	1,409.00	2,510.64	3,695.64
Payloader ‡ 196	—	665.63‡	1,632.07	1,142.66	—	1,220.75	2,212.41
Payloader ‡ 200	—	—	—	773.89	—	773.89	1,965.55

* = 6 months' cost. ‡ = 9 months' cost.

TABLE 2.—COST PER HOUR

Unit	Purchase price	Hours in use	Cost: Bare	Cost: Depreciation	Cost: Operator	Cost: Total*	Current rental charge
Link-Belt Crane	$4,447	400 E	$0.72	$1.86	$1.31	$3.89	$8.00
General	18,204	1,050	1.41	2.89	1.70	6.00	10.00
Unit	15,248	1,300	1.11	1.95	1.70	4.76	9.50
Quickway	7,110	1,200	2.09	0.99	1.50	4.58	6.00
Payloader	5,950	1,000 E	1.22	0.99	1.35	3.56	7.00
Payloader	7,150	1,000 E	0.77	1.19	1.35	3.31	7.00

E = Estimated.

* = 20% should be added to figures in this column for insurance and overheads.

truck, with no provision for carrying men, and also a few tow-about compressors on two rubber wheels.

Table 3 shows the average costs of operating each of the three types. A standard compressor on a special service truck is our favorite set-up. These seem to give less trouble than the power take-off units and are cheaper to operate. We have four makes of compressors and each make presents a different problem, when it is mounted on these service trucks. To save room on two makes, we have taken off the gasoline tanks and air receivers. The compressor motors are then supplied from the truck tank and the air receivers are mounted on the side. Lately, at least one company has developed an especially compact unit for cross-truck mounting.

Each of these compressors is equipped with a sump pump, a 60-lb breaker, an 80-lb breaker, two clay spades and two backfill tampers. The average life of these tools is slightly over ten years. Usually they are rebuilt after about six years of use at about one-half the cost of a new tool and then traded in, when air consumption becomes excessive, usually in about ten years. Table 4 shows the results of our experience with these pneumatic tools during 1949. Since many of these tools are comparatively new, operating costs over a period of years is likely to be somewhat higher than those shown. These tools are tested for air consumption about 10 times a year, but these costs are not shown in the table, since they are small and too hard to determine.

Costs vary considerably with the use to which machines are put and also with the care that they receive. A backhoe used only in sandy soil will last for years, if it is kept greased and oiled, while a similar machine used for digging rock trenches will have a much shorter life. There is also a great difference in operators. One pay-loader operator may nurse his machine along and yet put out lots of work, while another may bang and slam it around in rough spots and run up a large repair bill. During this present year, our three backhoes have been in almost constant use and, in addition, we have had a rented backhoe for several months and two others furnished to us by property developers. Observation has been that the unit cost of digging a foot of trench depends equally on the skill of the operator and the suitability and efficiency of the machine.

TABLE 3.—COMPRESSOR UNIT COSTS

Unit	Approx. first cost	Yearly: Compressor hours in use	Yearly: Truck mileage	Cost[1] per year	Cost per hour: Bare	Cost per hour: Depr.	Cost per hour: Total
St'd Compressor and Service Truck*	$4,400	1,040	4,760	$800.42	$0.77	$0.71	$1.48
P.T.O. Compressor and Service Truck**	4,000	1,040	4,760	925.90	0.88	0.64	1.52
St'd Compressor and Regular Truck‡	3,600	1,100	4,000	871.67	0.79	0.54	1.33
St'd Compressor on Pneumatic Tires‡	2,200	800	—	310.17	0.39	0.46	0.85

* = Average of 5 units.
** = Average of 4 units.
‡ = Average of 2 units.
[1] = Cost is divided about equally between truck and compressor.

TABLE 4.—ANNUAL COST OF OPERATING PNEUMATIC TOOLS IN 1949

	Number	Labor	Material	Total	Average
Caulking Hammers	5	$14.52	$28.19	$42.71	$8.54
Clay Diggers	24	101.64	330.90	432.54	18.02
Tampers	29	92.38	203.20	295.58	10.19
Paving Breakers	29	83.46	229.78	313.24	10.80
Sump Pumps	15	111.67	559.23	670.90	44.73
Air Wrenches	4	7.57	3.00	10.57	2.64

A NATIONAL ROSTER OF SANITARY AND PUBLIC-HEALTH ENGINEERS

BY FRANCIS B. ELDER*

[*Read September 13, 1949.*]

"SANITARY engineers have no single professional home. Because of their broad interests they are scattered through a dozen or more technical, scientific, and engineering organizations, with the choice of their allegiance depending in large measure on their particular interests and pursuits. Some belong to several of these societies; others to only one or two. Many sanitary engineers probably participate in none. Unfortunately there is not enough coördination or coöperation between these various groups looking toward the improvement of either the technical competence or the professional status of the sanitary engineer—there is no united front or common purpose. This situation may stem from a number of causes, including inertia, diversity of interests, and the absence of some cohesive influence to bring a measure of unity to this branch of the engineering profession. Perhaps the greatest possible service that can be rendered to sanitary engineers and to sanitary engineering would be to bring these diverse professional groups into closer acquaintanceship and understanding."

This is a statement of the Report of the Committee of the Sanitary Engineering Division, American Society of Civil Engineers, on Advancement of Sanitary Engineering, dated January 20, 1949[1]. The Report notes an apparent schism, resulting from the development of specialties within this engineering group, but goes on to observe that a single, independent organization of sanitary engineers would probably serve little purpose.

Any of you who have given consideration to the sanitary engineering profession must admit the correctness of the portion of the report quoted. Whether or not you agree with the undesirability of a single society for sanitary engineers, it seems evident that, before any

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[1]*Proceedings*, American Society of Civil Engineers, 75, 6:795 (June), 1949.

effective action can be taken to bring members of the engineering specialty into concerted action, it will be necessary to know who and where these engineers are. The work the American Public Health Association is doing in preparing a roster of sanitary and public-health engineers should be of interest to anyone considering common action between these professional men.

Suppose in a national emergency you were responsible for designating a group of men who would be competent to perform critical duties that required a high degree of training and experience. How would you go about it? Whom would you consider? How could you be sure to designate those individuals who might be required for this important work so that they would not be diverted to other less demanding jobs? Most of us know qualified engineers who spent their time during the past war as truck drivers, cooks or company clerks. Draft boards had little choice; the speed of mobilization and lack of predetermined job classification often made it impossible to channel men into proper positions.

Paul V. McNutt, Chairman of the War Manpower Commission, in January, 1943, announced the formation of a special committee within the Procurement and Assignment Service, which was given the responsibility of preparing a list of sanitary engineers. He said, "How many sanitary engineers there are in the United States who are already in some of the services directly or indirectly related to the war, no one knows."[2] With a comprehensive roster it should be possible to determine the whereabouts of the great majority of any group. We must avoid the unpreparedness that created so many difficulties in those days. Incidentally, recent studies show that civil engineers in the various military services during World War II were used in duties commensurate with their training and experience to the extent of about 50%. In other words, 50% of the civil engineers were used in duties that did not call on their training and experience as engineers or, if their training and experience was called on, it was to a minor degree.[3]

The American Public Health Association has signed a contract

[2]News release, Office of War Information, War Manpower Commission, PM-4285, for immediate release Monday, January 18, 1943.

[3]"Scientists in Uniform, World War II." Scientific Manpower Section, Research and Development Group, Logistics Division, GSC, Department of the Army, Washington, D. C.

with the National Security Resources Board for the preparation of a roster of sanitary and public-health engineers. The work in connection with this roster has been going on during 1949. It will be finished, for the purposes of the contract, the end of the year. However, so important is a current census of these engineers, that the Association plans to keep the roster up-to-date and enlarge it continually as new sources of information become available. We hope that funds can be found for this purpose. We hope that it will be financially possible to make the list available to other groups.

Obviously, before embarking on our assignment we needed a suitable definition of just what is meant by "sanitary" or "public-health engineer". We solved that problem rather easily by using the definition prepared in 1943 by the National Research Council. It reads: "The professional occupational title Sanitary Engineer shall apply to a graduate of a full 4-year, or longer, course leading to a Bachelor's, or higher, degree at a college or university of recognized standing with major study in engineering, who has fitted himself by suitable specialized training, study, and experience (a) to conceive, design, direct, and manage engineering works and projects developed, as a whole, or in part, for the protection and promotion of the public health, and (b) to investigate and correct engineering works and projects that are capable of injury to the public health by being or becoming faulty in conception, design, direction or management. The practice of sanitary engineering includes the following activities:

(a) Surveys, reports, designs, direction, management and investigation of:
(1) Waterworks or sewerage systems and closely related engineering structures.
(2) Projects relating to stream pollution, insect and vermin control or eradication, rural and camp sanitation, housing sanitation, and milk and food sanitation.
(3) Systems for the prevention of atmospheric pollution or the control of indoor air, especially the air of working spaces in industrial establishments (industrial-hygiene engineering).

(b) Professional research and laboratory work supporting the activities listed in (a).

(c) Responsible teaching of sanitary engineering and closely related subjects in colleges or universities of recognized standing."

The next step was the preparation of a master mailing list of all those who might comply with the definition, and then we ran into trouble. Of course, there was the listing prepared by the War Manpower Commission during the war. It has served as the nucleus for our list, but its value is limited because many of the addresses are APO's or army camps. Our next source was the membership lists of various engineering and technical societies. Position titles helped and personal knowledge of individuals aided us in selecting names from these directories, but there was no way to select one specific group that would represent the sanitary or public-health engineer. The lists of regular and reserve officers of the U. S. Public Health Service and of the old Sanitary Corps of the Army helped.

Obviously, many engineers do not hold commissions in either the Public Health Service or the Army. Likewise, we believe that an appreciable number do not belong to the national engineering societies. To overcome this difficulty we have used personal contacts. All of the state sanitary engineers have been asked for help. They have given us lists of engineers employed in state, county and local government. They have included engineers employed by industry or in private practice. Several of the large consulting organizations and engineering manufacturers have given us lists of their engineering employees.

You might suggest that the directories of the various state boards of professional registration would serve as good sources of information. We thought so until we had collected such directories. It is interesting that of the 42 state directories received, 27 give some sort of breakdown as to type of engineering specialty covered by registration. Fifteen state only that the individual is registered as a professional engineer or a land surveyor. Only 17 of the 27, giving some breakdown of specialty, list "sanitary engineering" as one of the professional groups. Since the funds available for the preparation of the roster are modest, these state directories have been of limited help. If we are able to continue work on the roster next year, we hope to derive some good from the 27 directories giving some degree of specialization, by sending a questionnaire to those general groups that might include sanitary or public-health engineers. Our present mailing list contains approximately 10,000 names.

The questionnaire was prepared for the job in hand. After

consulting with the NSRB to determine what information was required by our contract, we prepared one which should give the required information plus some additional data of interest to the profession. The first draft was sent out to more than 100 engineers for comment. On the basis of the response, the final form was selected. The questionnaire has been prepared so that the answers given by the recipients can be used directly for punching the information on machine record cards.

Many of you have received the questionnaire, but for those who have not yet had one a few words about the content of the questions may be appropriate. In addition to name, address, age, sex, marital status, present employer and nationality, there are questions on academic degrees and years of professional experience. This latter is divided into several groups: total years of professional engineering, sanitary or public-health engineering, and service with an official public-health agency. Requested information covers experience with any of the armed services, professional registration and membership in national engineering and technical societies. It should be evident that these data will have many uses in addition to that for which the NSBRB plans to use it.

Preparation of the roster has been somewhat complicated by the concurrent distribution of another questionnaire by the American Society of Mechanical Engineers for the Office of Naval Research. The purpose of this latter questionnaire is to provide information from which to prepare lists of individuals experienced in engineering research and development work. It covers the whole engineering profession, but from its nature will exclude many of the individuals in which we are interested. We are making every effort to prevent duplication. The Office of Naval Research has agreed to provide us with photostatic copies of all questionnaires submitted by those who give sanitary engineering as one of their proficiencies. We hope that any of you who may receive both questionnaires will be generous and complete both. The more comprehensive our roster can be made, the more valuable it will be. Any one of you who considers himself a sanitary or public-health engineer can be sure to receive our questionnaire by communicating with the Engineering Section Project, American Public Health Association, 1790 Broadway, New York 19, N. Y.

The uses for the completed roster are numerous. Obviously, the principal ones will be those to which the National Security Resources Board may put it. With the information available the NSRB, in case of a national emergency, will be in a position to designate those men with the general qualifications desired for various assignments. This will mean that the military services, industry, public health, etc., will receive their fair proportion of sanitary or public-health engineers available.

Any of you who are on academic staffs are confronted with the problem of estimating the number of matriculants desirable in any of the engineering specialties to satisfy future needs. The roster will provide a census of specialists now available.

All of us who are active in the affairs of the various professional societies know that one of the biggest difficulties in recruiting new members is in finding candidates. The roster can be of assistance in preparing lists of prospective members.

I want to recall part of the opening paragraph. You will remember that the ASCE committee on the Advancement of Sanitary Engineering decried the fact that there is no single organization to which sanitary and public-health engineers belong. It also questioned the need for a single organization but called for some means whereby common action and united effort could be secured for the sanitary-engineering group. When complete, the roster will provide the means for reaching practically all sanitary and public-health engineers.

We appreciate the opportunity extended to us by the officers and members of the New England Water Works Association to present this activity to you, because we feel the roster is important to all engineers working in that broad field of which public health is an important part.

PROCEEDINGS

November 1950 Meeting
Hotel Statler, Boston, Mass.
Thursday, November 16, 1950

President Thomas R. Camp in the Chair.

Secretary Knox announced the election of the following to membership in the Association:

Manuel E. Azevedo, Superintendent, Watchemoket Fire District, East Providence, R. I.; John F. Glacken, Chief Engineer, Water Department, Cambridge, Mass.; John P. Hennings, Engineer, Portland Water District, Portland, Me.; George A. Howland, III, Assistant Engineer, Metcalf & Eddy, Boston, Mass.; Clarence Francis Lamb, Partner, Waterman Engineering Co., Providence, R. I.; Byron O. McCoy, Hydraulic Engineer, Charles T. Main, Inc., Boston, Mass.; J. Carrell Morris, Associate Professor, Harvard University, Cambridge, Mass.; Philip W. Pease, Superintendent of Public Works, Dover, N. H.; Miner R. Stackpole, District Engineer, Water Resources Branch, U. S. Geological Survey, Augusta, Me.

A paper on "Water Distribution Systems Studied by a Complete Electrical Analogy" was read by Malcolm S. McIlroy, Professor of Electrical Engineering, College of Engineering, Cornell University, Ithaca, N. Y.

A paper on "Current Stream Flow Conditions" was read by Charles E. Knox, Hydraulic Engineer, U. S. Geological Survey, Boston, Mass.

J. A. Frank, Vice-President and General Manager of the National Water Main Cleaning Co., New York, N. Y., made some comments on the cleaning of water mains and showed two films, "Trenton Cleans Its Water Mains" and "Washington, D. C., Cleans Its Mains."

DECEMBER 1950 MEETING
HOTEL STATLER, BOSTON, MASS.
THURSDAY, DECEMBER 21, 1950

President Thomas R. Camp in the Chair.

Secretary Knox announced the election of the following to membership in the Association:

Morton Francis Sampson, Superintendent, Water Department, West Brookfield, Mass.; John P. Stewart, Manager, Water & Sewage Works Manufacturers Association, Inc.

Associate Member Reinstated:

Joseph Dixon Crucible Co., Boston, Mass.

A paper on "Preliminary Observations of the Storm of November, 1950, in New England" was read by Harvey B. Kinnison, District Engineer, U. S. Geological Survey, Boston, Mass.

A paper on "Laying Subaqueous Pressure Mains" was read by Stephen Haseltine, Project Engineer, Metcalf & Eddy, Boston, Mass.

A paper on "The Desalting of Saline Waters", prepared by Edward W. Moore, Associate Professor, Harvard University, Cambridge, Mass., was read, in the absence of Professor Moore, by President Camp.

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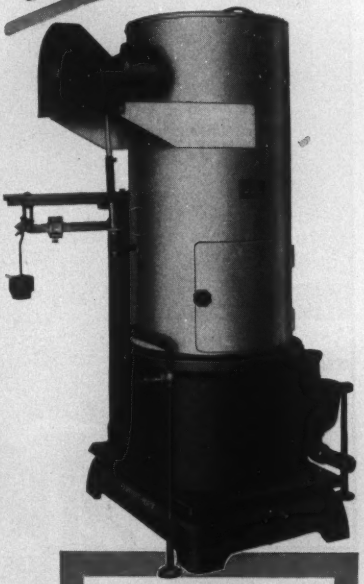

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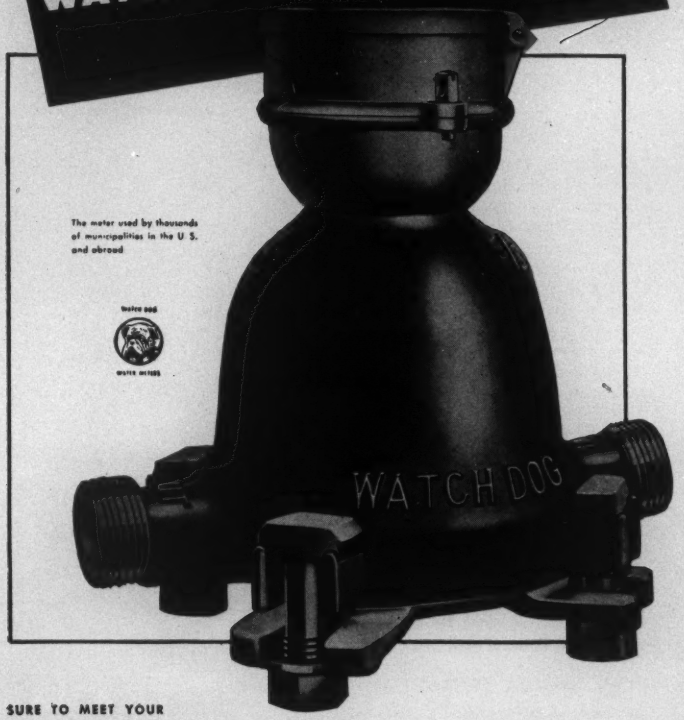

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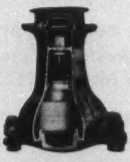

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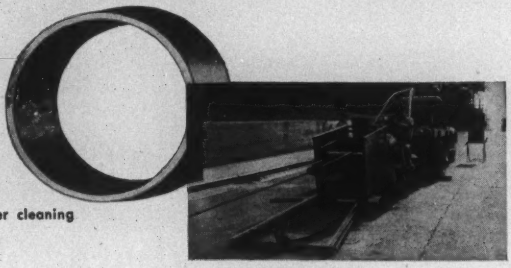

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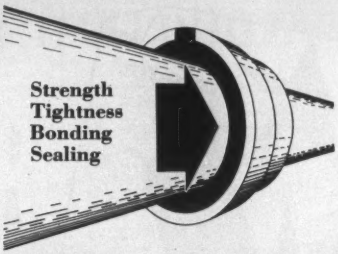

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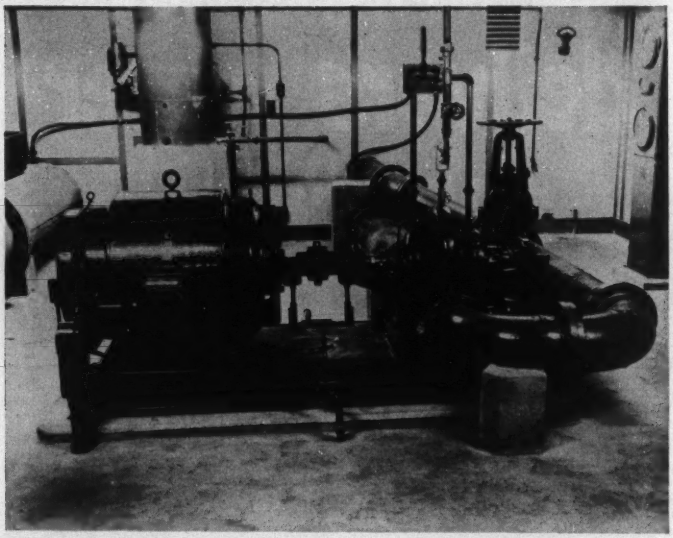

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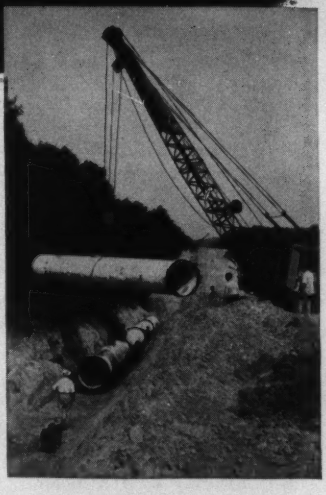

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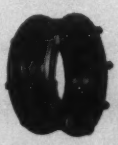
You save on maintenance because the flexible-tight Dresser line "lives in the ground" comfortably and because modern glass-smooth linings assure high-sustained carrying capacity, life-long service.

See your Dresser Sales Engineer, or write today for literature.

In Springfield, Mass., as many as 40 long lengths of pipe were laid and joined in an eight-hour day, using a two-man joining crew.

Be sure you get the best line at the best price. Put steel pipe and Dresser Couplings in your specifications.

DRESSER "FLEXIBLE-TIGHT" COUPLINGS



Dresser Manufacturing Division, 59 Fisher Ave., Bradford, Pa. (One of the Dresser Industries). In Texas: 1121 Rothwell St., Houston. In Canada: 629 Adelaide St., W., Toronto, Ont. Sales Offices: New York, Chicago, Houston, Philadelphia, San Francisco.

From Break to Service *in 11 minutes . . .*

• **THE KENNEDY SAFETOP** is the only hydrant with the threaded breaking ring that gives positive connection and rigid alignment of the two standpipe sections. Extensive tests and actual service reports show that the Kennedy *Safetop* can stand as tough a blow as the conventional hydrant without damage. But under a smashing impact, it always breaks cleanly at the breaking ring, without damage to working parts.

SHEARED OFF by a heavy road-scraper at 1:26, the Kennedy *Safetop* breaks evenly at the ground level.

Photos taken at N. Y. State Section meeting, A.W.W.A., April 1949.

WITH ONLY an inexpensive *Safetop* Repair Kit and a few common tools, one man can permanently repair the Kennedy *Safetop*.

NO NEED FOR DIGGING because breakage is all above ground . . . no flooding because compression-type valve closes with water pressure.

IN JUST 11 MINUTES the Kennedy *Safetop* is back in service . . . working as smoothly and efficiently as if nothing had happened.

WRITE FOR SAFETOP BULLETIN 105

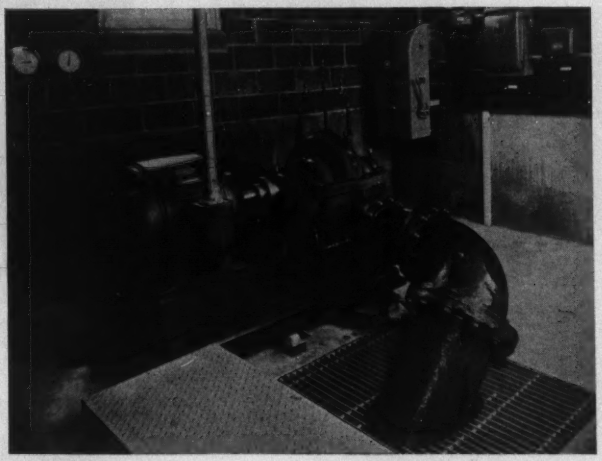
THE **KENNEDY**
VALVE MFG. CO. • ELMIRA, N.Y.

Est. 1877

VALVES • PIPE FITTINGS • FIRE HYDRANTS

EMERSON BROOK STATION

Danvers, Massachusetts



Critical water shortage for the Town of Danvers, Mass., necessitated immediate new source of water supply, which was found in Emerson Brook.

A 4 MGD De Laval Pump was selected for this supplementary supply because of the satisfactory performance of the De Laval Pumps at their main pumping station.

Elson T. Killam, New York City, was the Consulting Engineer for the project.

TURBINE EQUIPMENT COMPANY OF NEW ENGLAND

80 Federal Street **Phone LIberty 2-5993** **Boston 10, Mass.**

New England Representatives for

DE LAVAL STEAM TURBINE COMPANY

TRENTON, NEW JERSEY

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Don't take chances with inferior caulking lead which may have been manufactured from scrap material containing a large percentage of impurities.

When present in a caulked joint, impurities on the surface will corrode and cause weak spots. The stresses due to normal pipe movement concentrate at these areas and failure results.

Our lead, both in ingot and wool form, is made from selected metals and carries the Lead Industries Association Seal of Approval as a guarantee of its quality.

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CATALOG No. 5200
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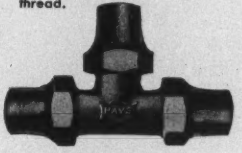
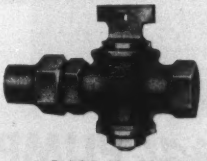
HAYS Manufacturing Company is one of the largest making a complete line of water service products, and for 80 years has enjoyed the prestige earned by unremitting insistence upon high quality. The HAYS line of fittings and other products is famous throughout the world for easy installation and a long life of trouble-free service.

All HAYS water works fittings are interchangeable with those of other manufacturers and corporation stops can be installed with any standard tapping machine equipment. They are made of highest quality 85-5-5-5 bronze, plugs are ground for perfect fit, specially lubricated for permanent easy turning, and hydrostatically tested at 200 pounds or more. Write for the new HAYS catalog showing the complete HAYS line of water works products.

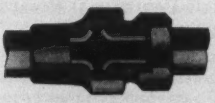


CATALOG No. 5622
Hays Tee for copper to copper to copper connection.



CATALOG No. 5050
Hays Curb Stop for iron pipe to copper service connection.

CATALOG No. 5628
Hays Elbow for Male iron pipe to copper connection.



CATALOG No. 5610
Hays Two Part Union for copper to copper connection.

CATALOG No. 5605
Hays Coupling for Male Iron pipe to copper connection.

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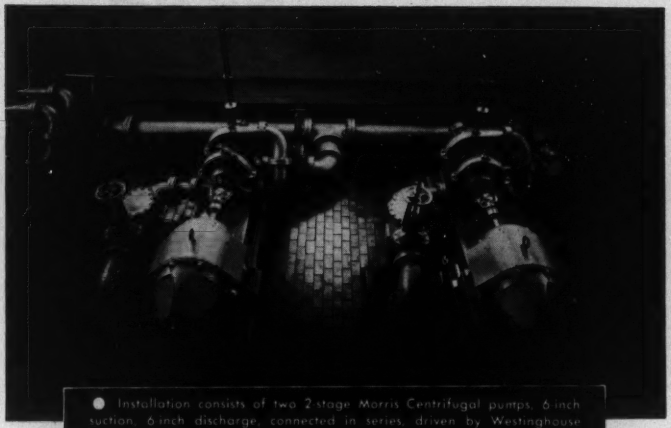
COPPER BRASS LEAD IRON
WATER WORKS PRODUCTS
HAYS MANUFACTURING CO., ERIE, PA.

Pumping Concord's Water

FOR 19 YEARS...



● Installation consists of two 2-stage Morris Centrifugal pumps, 6-inch suction, 6-inch discharge, connected in series, driven by Westinghouse 125 H.P. motors at a speed of 1740 R.P.M.; capacity of each unit 1145 gallons per minute with suction lift of 15 feet and discharge head 286 feet.

The third unit is a 3-stage Morris Centrifugal pump connected in series, driven by a 175 H.P. Sterling Dolphin gas engine, 1200 R.P.M., 1145 gallons per minute.

MORRIS *Centrifugal* PUMPS

In 1930, the contract for pumping equipment in the new Meadow Station at Concord, New Hampshire, was awarded to the Starkweather Engineering Company of Newtonville, Mass. Three Morris Centrifugal Pumps were then installed—nineteen years ago.

Since then the Morris Pumps have given such excellent service, according to theSuperintendent of the Water Department, that the Town ordered, and now has in operation, a fourth Morris Pump for the Main Station..

Another example of MORRIS' year in, year out reliability with maximum EFFICIENCY . . .

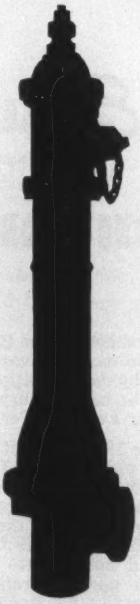
There is a Morris Pump for every job. Write us for specification and operation data best suited to your needs. No charge or obligation.

MORRIS MACHINE WORKS, Baldwinsville, N. Y.
Starkweather Engineering Co., Inc.
264 Walnut St. Newtonville 60, Mass.

MORRIS *Centrifugal Pumps*

EDDY

Valves and Hydrants

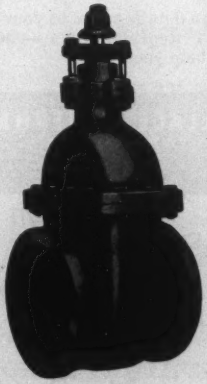


Distinctive Features of the EDDY Valves

ONLY three parts are moved by the Stem—the ball and the two gates. Each gate is hung from one of the trunnions on the ball. A convex surface at the base of each trunnion fits a concave surface on the back of the gate. This allows the gates to adjust themselves properly to their seats. . . . The gates, being free to revolve on the trunnions, do not always seat in the same position. Gates are center bearing and adjustable. They are forced to their seats with equal pressure at all points. There are two hooks on the ball on sizes 4-inch and larger, which loosely engage with the gates.

Distinctive Features of Our New Swivel Top Hydrants

THIS new hydrant has all the advantages of the popular EDDY fire hydrant, plus several additional features. . . . Nozzles are in a short flanged section of the standpipe, which may be unbolted and turned to different positions. . . . Should the standpipe be broken, only the casting below the swivel head need be replaced. . . . To raise the hydrant to conform to a new grading, simply insert a flanged extension piece below the swivelhead. No digging. To add a steamer nozzle at any time, it is only necessary to replace the swivel head with one having a steamer nozzle.

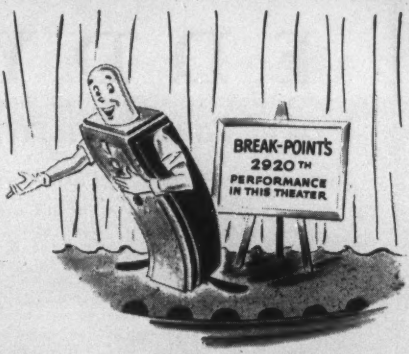


Besides valves and hydrants to meet the most exacting demands of waterworks service, the complete EDDY Line includes: valves for sewage disposal works; valves for steam, gas and oil; check valves, foot valves, plug valves, shear gates, indicator posts, etc. EDDY valves are made in three classes: Iron Body Bronze Mounted, All Bronze, and All Iron Valves.

Eddy Valve Co.

WATERFORD NEW YORK

8 YEARS AND STILL GOING STRONG



The ability of the Break-Point Process to meet the various demands of day by day operation is aptly shown by the case history of a municipal water works in Pennsylvania.

Since 1941, when it was installed at this plant by W&T Engineers, the Break-Point Process has played a major role in producing a pure, sparkling water for the system's many consumers. It has completely eliminated complaints on tastes and odors and has raised the finished water quality to such a high level that tests show *no* gas formers and *no* bacteria on the plates. In addition, a staff report continues, the Break-Point Process was of particular value in keeping the water acceptable to consumers during an emergency plant overload of 120%.

These accomplishments and such additional benefits as longer filter runs and iron and manganese removal are typical of what you receive with the Break-Point Process backed by W&T Equipment.

In the complete line of W&T chlorinating equipment, proved by over 35 years' experience all over the world, there is a chlorinator that will give *your* plant these benefits, too.

For more details write to your nearest W&T Representative — he'll be glad to help you.

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NEWARK 1, NEW JERSEY • REPRESENTED IN PRINCIPAL CITIES

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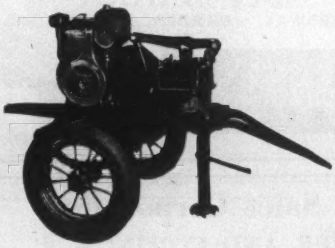
EDSON

PUMPS and ACCESSORIES



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Depco Centrifugals

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Special Castings *Short Body B. & S. Specials*

Warren (WF) *Spun Centrifugally Cast Iron Pipe*

WORKS: PHILLIPSBURG, N. J. and EVERETT, MASS.

Large Stock Enables Us to Make Prompt Shipments

Get Full Service From Old Mains

The most practical way to meet today's overload demand is to clean clogged water mains. FLEXIBLE Underground Pipe Cleaning Co., specializes in such jobs— any size—2" to 72".

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Pipe Founders Sales Corporation

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FOR

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Special Flanged and Bell and Spigot Castings
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1879—ROSS— 1879

AUTOMATIC VALVES

Controls elevation of water in tanks, basins and reservoirs

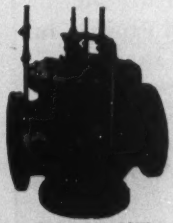
ALTITUDE VALVE

1. Single Acting
2. Double Acting

Maintains desired discharge pressure regardless of change in rate of flow

REDUCING VALVE

Regulates pressures in gravity and pump systems; between reservoirs and zones of different pressures, etc.



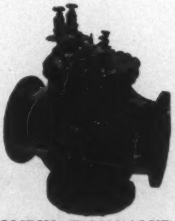
Maintains levels in tank, reservoir or basin

1. As direct acting

2. Pilot operated and with float traveling between two stops, for upper and lower limit of water elevation.

FLOAT VALVE

A self contained unit, with controls three or more automatic



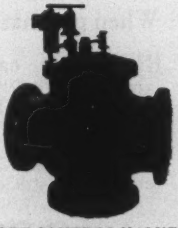
COMBINATION VALVE

Combination automatic control both directions through the valve.

Maintains safe operating pressures for conduits, distribution and pump discharge

SURGE-RELIEF VALVE

Electric remote control—solenoid or motor can be furnished



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Adapted for use as primary or secondary control on any of the hydraulically controlled or operated valves.

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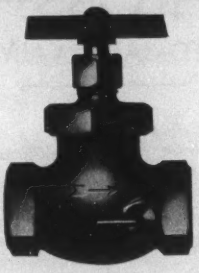

Fig. 250

RED HED COMPRESSION VALVE

A Sturdy Well Built Valve for Long, Hard Service. 85 Per Cent Virgin Copper—250 Pound Test. Independent Drip—Renewable Seats.

Seldom is an inferior article imitated. RED HED Brass Goods have long been recognized for their high quality of material and workmanship.

When purchasing Water Works Brass Goods, the name, RED HED, cast or marked on each piece, will assure the buyer of less trouble, annoyance, and expense in replacements.

RED HED MFG. CO.

Manufacturers of

RED HED Brass Goods for Water Works

368 Congress Street **Boston 10, Mass.**

No question about it; the most popular beverage of all is good drinking water—water that tastes right, smells right and looks right.

And there's no reason for water not to be "right." Where Welsbach Ozonating equipment is used, consumers know the pleasure of drinking water free from disagreeable chlorinous odors, offensive "medicinal" tastes and objectionable color.

The biggest Ozone installation in the world (serving the Belmont filtration area in Philadelphia) proves that through Welsbach, cities can get the most efficient type of water treatment at a cost that's kind to the taxpayers.

• • •

Everybody wants improved drinking water—and all communities can now have it. Water technicians, city officials and consulting engineers particularly will be interested in the Welsbach-Ozone story. They are invited to write about their water difficulties to The Welsbach Corporation. A frank, factual analysis will be made—at no cost or obligation. Also ask for, "Are Ruthless Thursdays Really Necessary?", the picture story booklet about the Welsbach-Ozone process and equipment.

THE WELSBACH CORPORATION

Ozone Processes Division

1500 Walnut Street, Philadelphia 2, Pennsylvania

Tegul-MINERALEAD*

AND

HYDE-RO RINGS

the best way

to join

bell and spigot pipe

Tegul-Mineralead, the original plasticized sulfur compound joint, is easy and clean to work with, economical, too — needs no skilled labor, caulking or deep bell holes. HYDE-RO RINGS, rubber ring packing, are recommended for use with Tegul-Mineralead. Please write us at 17 Walnut Street, Mertztown, Penna., and request Bulletin No. M10-1 and M10-5.

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CEMENT LINED SERVICE PIPE:—

Resists Corrosion

Has proven practical for nearly three-quarters of a century

Immediate delivery can be made to waterworks on both wrought iron and steel, black or galvanized.

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Manufacturers of CENTRIFUGAL CEMENT LINED PIPE and LEAD AND TIN LINED FITTINGS

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Ask for quotations

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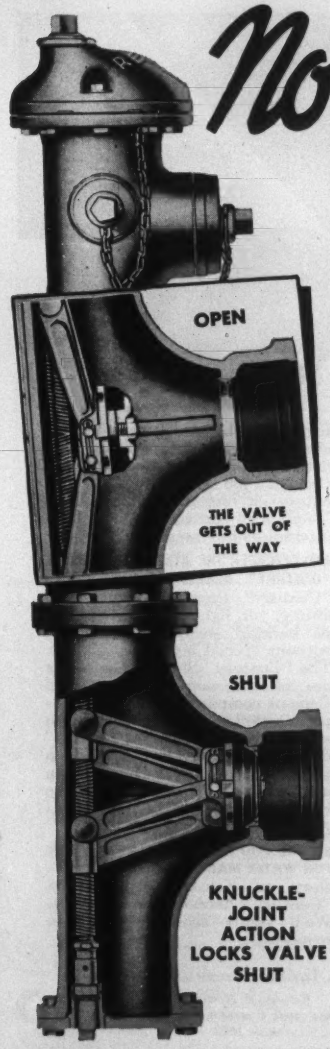

Above hydrant shown with "hub end" inlet. Also made in "flange end" type; and with mechanical joint.

No sticking cussing

more water quicker

from every

RENSSELAER

A hydrant should open quickly and easily – deliver a flood of water fast.

It should shut tight and STAY tight – locked shut and secure.

That's exactly what every Rensselaer Hydrant does. The main valve opens with the pressure. In full open position, the valve is backed against the casing, completely out of the waterway. Loss of head is minimized.

The powerful knuckle-joint action of steel forgings bearing against the case mechanically closes the valve and locks it shut. Valve has special rubber face that will not scar or leak.

Other features include solid bronze vital parts, for long life. Fast non-clog draining. No water-hammer. No flooding if barrel is broken. No digging to repair broken barrel. And one man can easily remove and replace all working parts, without special tools or hoist, just by removing the head.

There are thousands of Rensselaer Hydrants in satisfactory service. More are being put in all the time.

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Hydrants • Gate Valves • Square Bottom Valves
Check Valves • Tapping Sleeves and Valves • Air Release Valves
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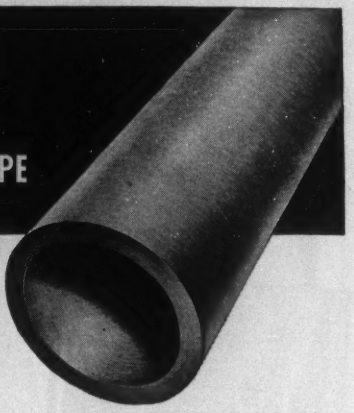
The inside story of "Century" ASBESTOS-CEMENT PIPE



BEFORE you specify pipe for water mains, be sure to consider the *inside*, as well as the outside. Here's what you'll find inside "Century" Asbestos-Cement Pipe:

A SMOOTH, CLEAN BORE THAT STAYS THAT WAY!—"Century" Asbestos-Cement Pipe is formed on a smooth, steel mandrel—the pipe's interior takes its surface from this . . . permanently smooth! (Williams and Hazen Constant "C" is conservatively placed at 140 for "Century" Asbestos-Cement Pipe).

A NON-TUBERCULATING SURFACE! Tuberculation, one of the pipe enemies from within, first increases friction, then reduces flow area. This cannot happen with "Century" Asbestos-Cement Pipe. It is entirely non-metallic. Initial flow capacity remains constant!

A SURFACE THAT RESISTS CORROSION! Though corrosion is usually an *external* enemy of pipe, certain combinations of water chemicals, together with electrolysis, can bring about internal pipe corrosion and deterioration. "Century" Asbestos-Cement Pipe is entirely mineral in nature—is immune to electrolysis—resists all corrosion factors, both internal and external!

Installation crew laying "Century" Pipe through wooded area.

AND CONSIDER THE OTHER FEATURES OF "CENTURY" ASBESTOS-CEMENT PIPE: "Century" Pipe is exceptionally strong, yet, light in weight. It can be handled easily, laid quickly, without special laying equipment. The "Century" Simplex Couplings are of the same Asbestos and Cement composition as the pipe—permit rapid, easy laying of both straight runs and curves up to 5° deflection per pipe length. And, so permanently strong and unchanging is "Century" Pipe, that it can be recovered and laid in its original pressure class!

BEFORE YOU BUY OR SPECIFY ANY PIPE FOR WATER MAINS, get the complete story on Keasbey & Mattison "Century" Asbestos-Cement Pipe. We'll gladly send details upon request.

Nature made Asbestos . . .

Keasbey & Mattison has made it serve mankind since 1873

K&M best in asbestos

KEASBEY & MATTISON

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CEMENT LINED PIPE. (See Pipe, Cement Lined.)

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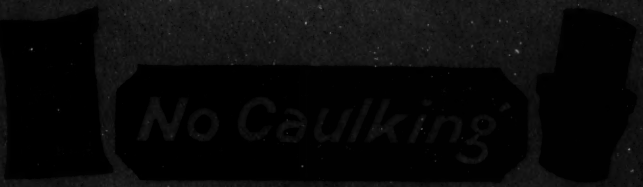
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